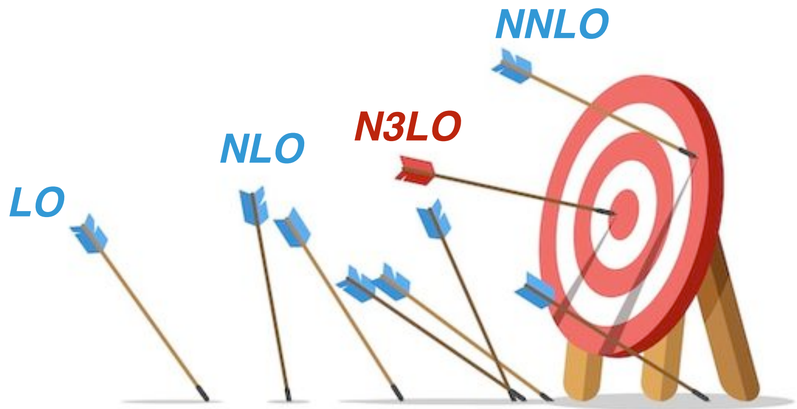
QCD and Monte Carlo event generators (Lecture 2 — Hands-on session)

Marius Wiesemann

Max-Planck-Institut für Physik



BND summer school 2024

Blankenberge (Belgium), September 2-12th, 2024


FREE YOUR MIND
THE MATRIX

Outline

- MATRIX features
  - processes, q_T subtraction + cutoff extrapolation, extensions, …
- How to compile the code + How to run the code ➔ ***hands on!***
  - basic information & some hidden features
- Folder structure
- Implement/access/understand certain features: ➔ ***hands on!***
  - changing the inputs (change precision, change QCD/EW order, change machine energy…)
  - adding a distribution & comparison to ATLAS data
  - "normal" processes vs. photon processes

The MATRIX framework

[Grazzini, Kallweit, MW '17] https://matrix.hepforge.org/

Amplitudes

OpenLoops (Collier, CutTOols, ...)	Dedicated 2-loop codes (VVamp, GiNaC, tdhpl, ...)

Munich

MUlti-chaNnel Integrator at Swiss (CH) precision

q_T subtraction $\Leftrightarrow$ q_T resummation

NNLO

NNLL

Matrix

Munich Automates qT Subtraction and Resummation to Integrate X-sections.

The MATRIX team

Massimiliano "Morpheus" Grazzini

Stefan "Neo" Kallweit

Marius "Trinity" Wiesemann

The MATRIX team

Luca "Cypher" Rottocore/ Buonottoli

Massimiliano "Morpheus" Grazzini

Stefan "Neo" Kallweit

Marius "Trinity" Wiesemann

Javier "Trinity" Mazzitelli

Simone "Trinity" Devoto

Chiara "Trinity" Savoini

MATRIX processes

process	status	comment
pp→Z/γ*(→ℓℓ/νν)	✓	validated analytically + FEWZ
pp→W(→ℓν)	✓	validated with FEWZ, NNLOjet
pp→H	✓	validated analytically (by SusHi)
pp→γγ	✓	validated with 2γNNLO
pp→Zγ→ℓℓγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→Zγ→νγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→Wγ→ℓνγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→γγγ	✓	[Kallweit, Sotnikov, MW '20]
pp→ZZ	✓	[Cascioli et al. '14]
pp→ZZ→ℓℓℓℓ	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓℓ'ℓ'	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓν'ν'	✓	[Kallweit, MW '18]
pp→ZZ/WW→ℓℓνν	✓	[Kallweit, MW '18]
pp→WW	✓	[Gehrmann et al. '14]
pp→WW→ℓν ℓ'ν'	✓	[Grazzini, Kallweit, Pozzorini, Rathlev, MW '16]
pp→WZ	✓	[Grazzini, Kallweit, Rathlev, MW '16]
pp→WZ→ℓνℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→WZ→ℓ'ν'ℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→tt	✓	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Sargsyan, '19]

not yet in public release

process	status	comment
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pp→ttH	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Savioni, '19]
pp→bbW	(✓)	[Buonocore, Devoto, Kallweit, Mazzitelli, Rottoli, Savoini, '23]
pp→ttW	(✓)	[Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini, '23]

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pp→WW→ℓν ℓ'ν'	✓	[Grazzini, Kallweit, Pozzorini, Rathlev, MW '16]
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pp→WZ→ℓνℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→WZ→ℓ'ν'ℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→tt	✓	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Sargsyan, '19]

single boson processes

not yet in public release

process	status	comment
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single boson processes

photon processes

not yet in public release

process	status	comment
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pp→ttH	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Savioni, '19]
pp→bbW	(✓)	[Buonocore, Devoto, Kallweit, Mazzitelli, Rottoli, Savoini, '23]
pp→ttW	(✓)	[Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini, '23]

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pp→ZZ	✓	[Cascioli et al. '14]
pp→ZZ→ℓℓℓℓ	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓℓ'ℓ'	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓν'ν'	✓	[Kallweit, MW '18]
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pp→WZ→ℓ'ν'ℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→tt	✓	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Sargsyan, '19]

single boson processes

photon processes

massive diboson processes

not yet in public release

process	status	comment
pp→HH	(✓)	[Grazzini, Kallweit, Rathlev '15]
pp→bb	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, '20]
pp→ttH	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Savioni, '19]
pp→bbW	(✓)	[Buonocore, Devoto, Kallweit, Mazzitelli, Rottoli, Savoini, '23]
pp→ttW	(✓)	[Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini, '23]

MATRIX processes

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pp→γγ	✓	validated with 2γNNLO
pp→Zγ→ℓℓγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→Zγ→νγ	✓	[Grazzini, Kallweit, Rathlev '15]
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pp→ZZ	✓	[Cascioli et al. '14]
pp→ZZ→ℓℓℓℓ	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓℓ'ℓ'	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
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pp→ZZ/WW→ℓℓνν	✓	[Kallweit, MW '18]
pp→WW	✓	[Gehrmann et al. '14]
pp→WW→ℓν ℓ'ν'	✓	[Grazzini, Kallweit, Pozzorini, Rathlev, MW '16]
pp→WZ	✓	[Grazzini, Kallweit, Rathlev, MW '16]
pp→WZ→ℓνℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→WZ→ℓ'ν'ℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→tt	✓	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Sargsyan, '19]

single boson processes

photon processes

massive diboson processes

heavy-quark processes

not yet in public release

process	status	comment
pp→HH	(✓)	[Grazzini, Kallweit, Rathlev '15]
pp→bb	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, '20]
pp→ttH	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Savioni, '19]
pp→bbW	(✓)	[Buonocore, Devoto, Kallweit, Mazzitelli, Rottoli, Savoini, '23]
pp→ttW	(✓)	[Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini, '23]

MATRIX processes

process	status	comment
pp→Z/γ*(→ℓℓ/νν)	✓	validated analytically + FEWZ
pp→W(→ℓν)	✓	validated with FEWZ, NNLOjet
pp→H	✓	validated analytically (by SusHi)
pp→γγ	✓	validated with 2γNNLO
pp→Zγ→ℓℓγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→Zγ→νγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→Wγ→ℓνγ	✓	[Grazzini, Kallweit, Rathlev '15]
pp→γγγ	✓	[Kallweit, Sotnikov, MW '20]
pp→ZZ	✓	[Cascioli et al. '14]
pp→ZZ→ℓℓℓℓ	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓℓ'ℓ'	✓	[Grazzini, Kallweit, Rathlev '15], [Kallweit, MW '18]
pp→ZZ→ℓℓν'ν'	✓	[Kallweit, MW '18]
pp→ZZ/WW→ℓℓνν	✓	[Kallweit, MW '18]
pp→WW	✓	[Gehrmann et al. '14]
pp→WW→ℓν ℓ'ν'	✓	[Grazzini, Kallweit, Pozzorini, Rathlev, MW '16]
pp→WZ	✓	[Grazzini, Kallweit, Rathlev, MW '16]
pp→WZ→ℓνℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→WZ→ℓ'ν'ℓℓ	✓	[Grazzini, Kallweit, Rathlev, MW '17]
pp→tt	✓	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Sargsyan, '19]

single boson processes

photon processes

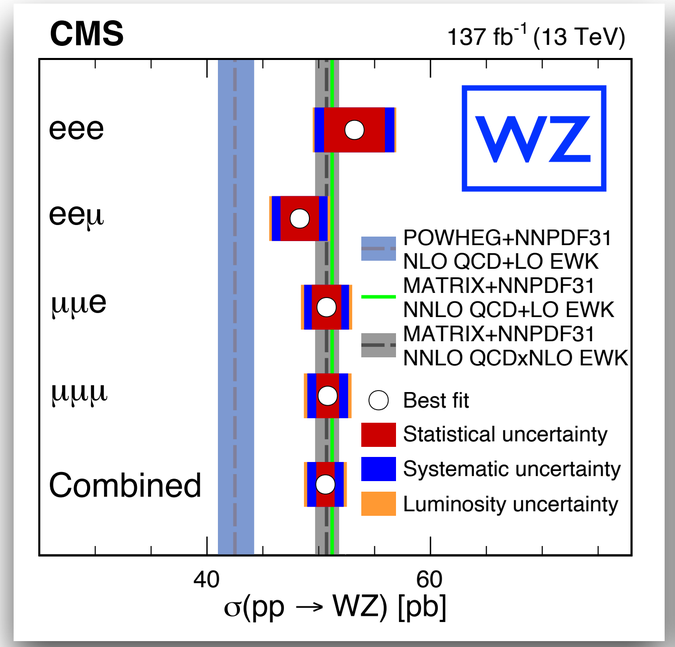
massive diboson processes

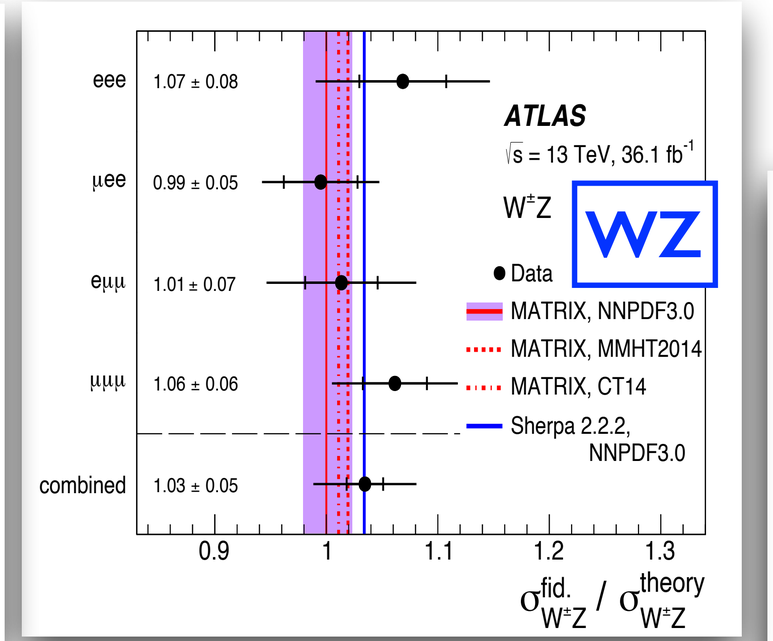
heavy-quark processes

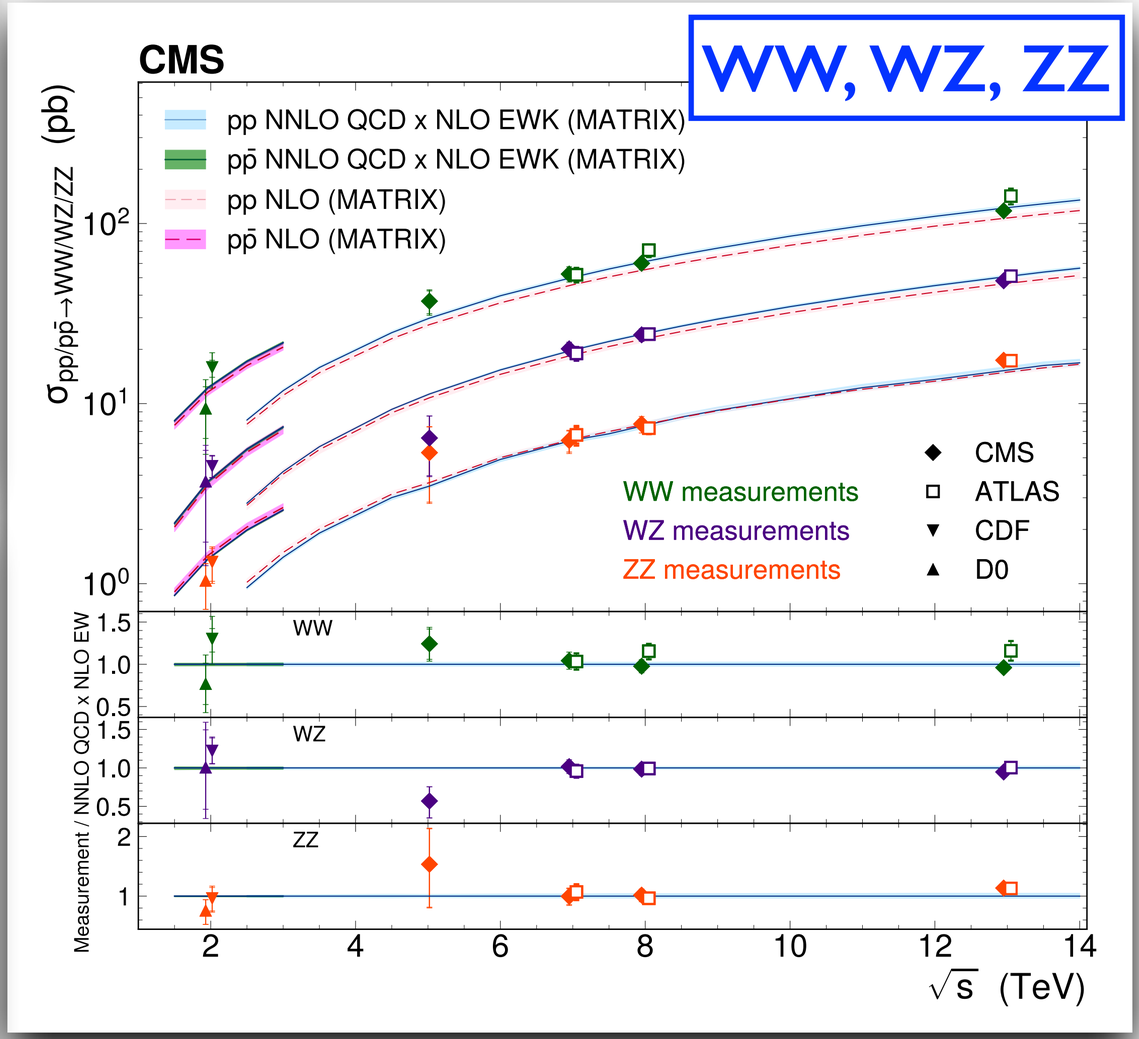
heavy-quark + colour singlet processes

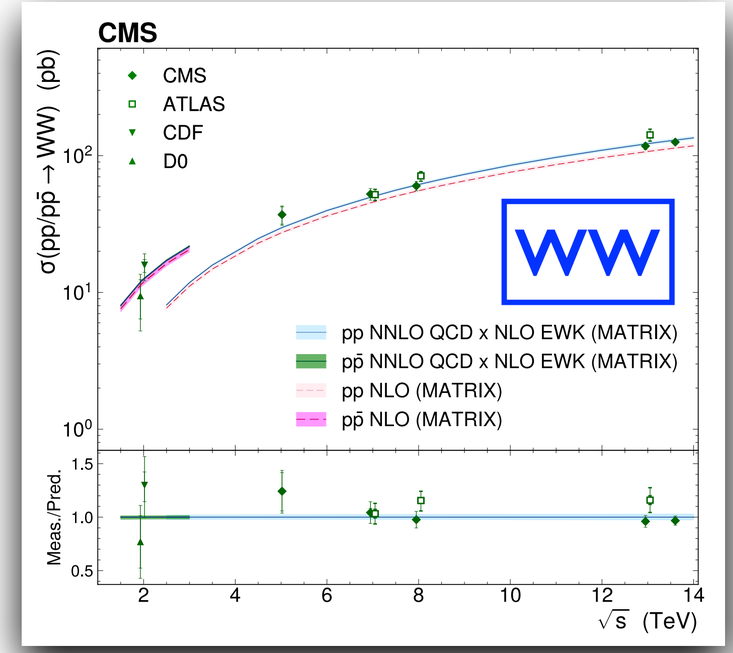
not yet in public release

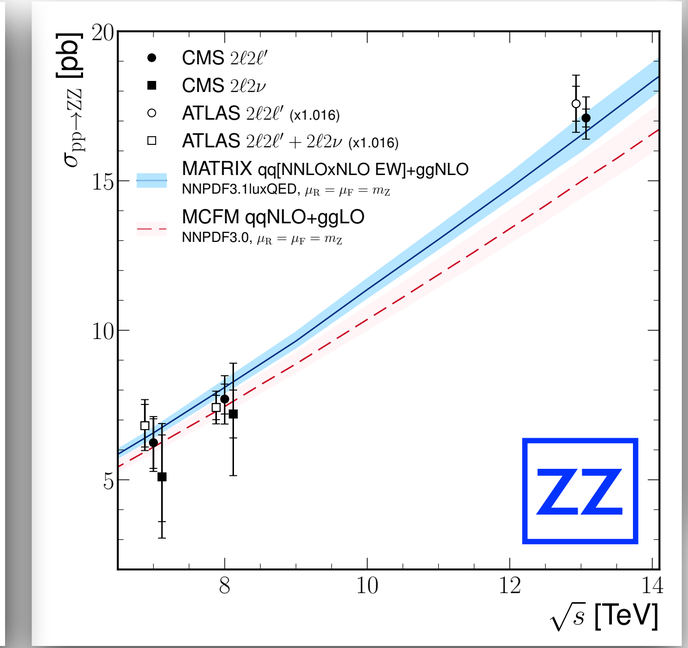
process	status	comment
pp→HH	(✓)	[Grazzini, Kallweit, Rathlev '15]
pp→bb	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, '20]
pp→ttH	(✓)	[Catani, Devoto, Grazzini, Kallweit, Mazzitelli, Savioni, '19]
pp→bbW	(✓)	[Buonocore, Devoto, Kallweit, Mazzitelli, Rottoli, Savoini, '23]
pp→ttW	(✓)	[Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini, '23]

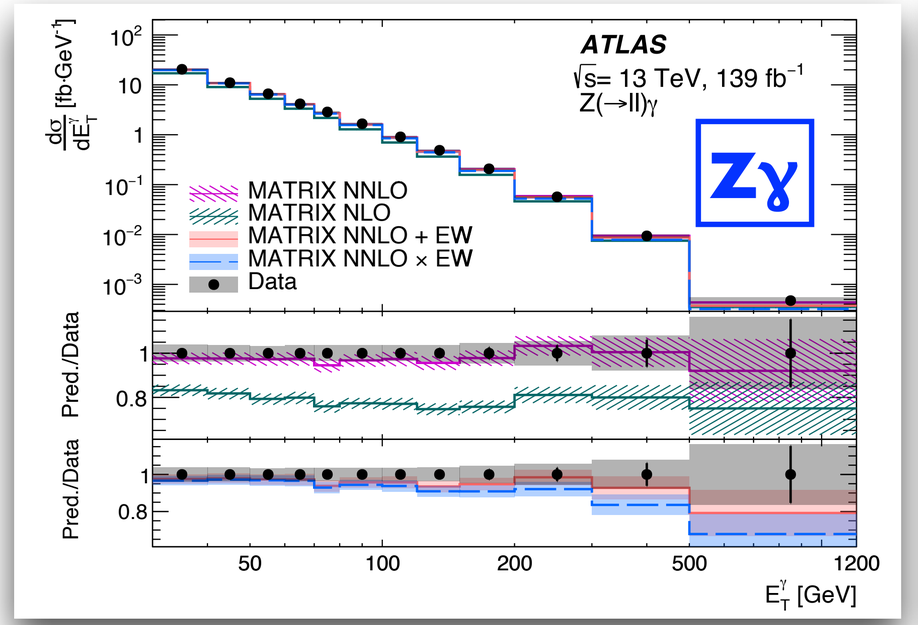

CMS
137 fb^{-1} (13 TeV)
WZ
eee
eeμ
μμe
μμμ
Combined
POWHEG+NNPDF31 NLO QCD+LO EWK
MATRIX+NNPDF31 NNLO QCD+LO EWK
MATRIX+NNPDF31 NNLO QCDxNLO EWK
Best fit
Statistical uncertainty
Systematic uncertainty
Luminosity uncertainty
40
60
σ(pp → WZ) [pb]

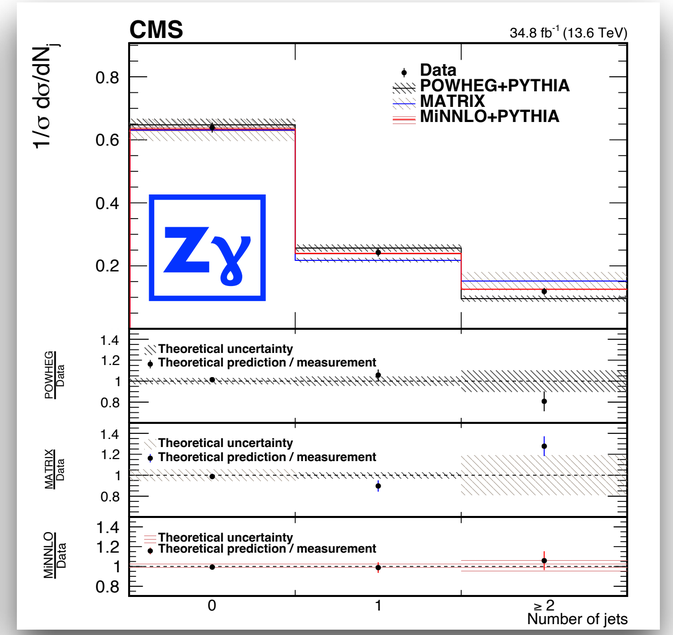

eee 1.07 ± 0.08
μee 0.99 ± 0.05
eμμ 1.01 ± 0.07
μμμ 1.06 ± 0.06
combined 1.03 ± 0.05
ATLAS
√s = 13 TeV, 36.1 fb^{-1}
W$^{\pm}$Z
WZ
Data
MATRIX, NNPDF3.0
MATRIX, MMHT2014
MATRIX, CT14
Sherpa 2.2.2, NNPDF3.0
0.9
1
1.1
1.2
1.3
σ$^{fid.}_{W^{\pm}Z}$ / σ$^{theory}_{W^{\pm}Z}$

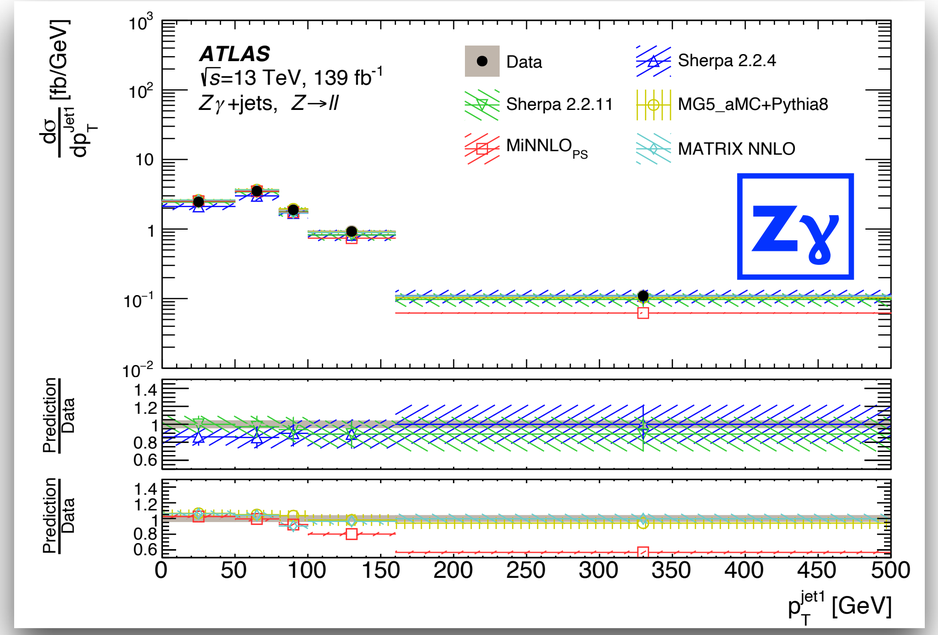

WW, WZ, ZZ
CMS
pp NNLO QCD x NLO EWK (MATRIX)
pp̄ NNLO QCD x NLO EWK (MATRIX)
pp NLO (MATRIX)
pp̄ NLO (MATRIX)
σ$_{pp/p\bar{p}\to WW/WZ/ZZ}$ (pb)
WW measurements
WZ measurements
ZZ measurements
CMS
ATLAS
CDF
D0
WW
WZ
ZZ
Measurement / NNLO QCD x NLO EW
√s (TeV)

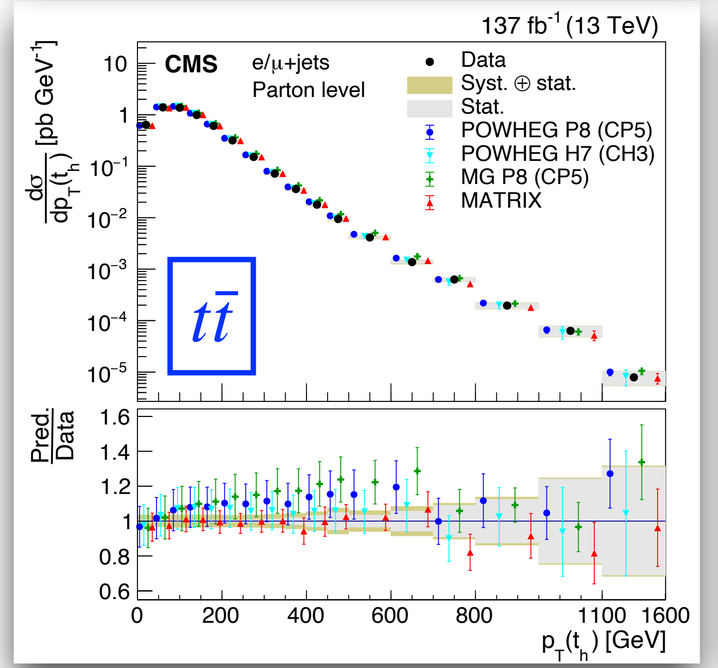

CMS
CMS
ATLAS
CDF
D0
WW
pp NNLO QCD x NLO EWK (MATRIX)
pp̄ NNLO QCD x NLO EWK (MATRIX)
pp NLO (MATRIX)
pp̄ NLO (MATRIX)
σ(pp/pp̄ → WW) (pb)
Meas./Pred.
√s (TeV)

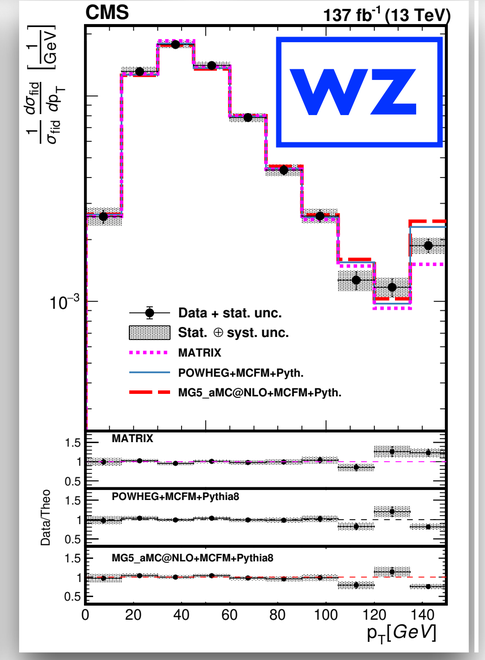

CMS 2ℓ2ℓ′
CMS 2ℓ2ν
ATLAS 2ℓ2ℓ′ (x1.016)
ATLAS 2ℓ2ℓ′ + 2ℓ2ν (x1.016)
MATRIX qq[NNLOxNLO EW]+ggNLO
NNPDF3.1luxQED, μ$_R$ = μ$_F$ = m$_Z$
MCFM qqNLO+ggLO
NNPDF3.0, μ$_R$ = μ$_F$ = m$_Z$
ZZ
σ$_{pp\to ZZ}$ [pb]
√s [TeV]

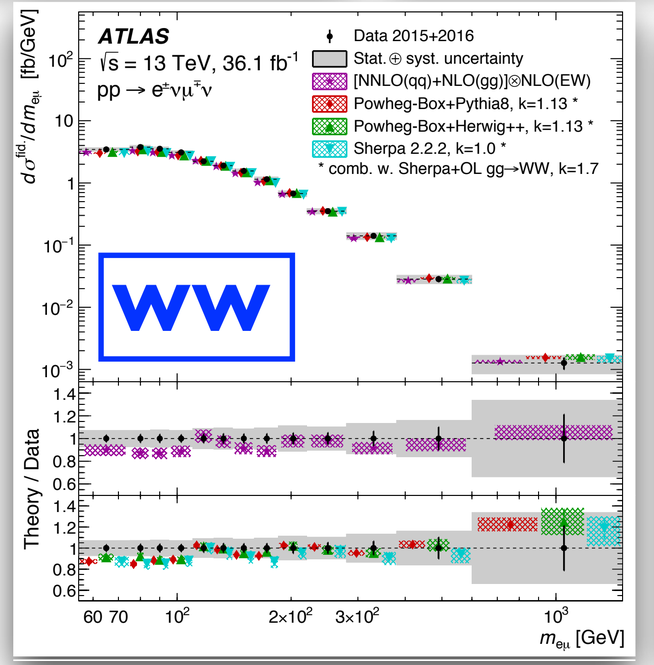

ATLAS
√s= 13 TeV, 139 fb⁻¹
Z(→ll)γ
Zγ
MATRIX NNLO
MATRIX NLO
MATRIX NNLO + EW
MATRIX NNLO × EW
Data
Pred./Data
E_T^γ [GeV]

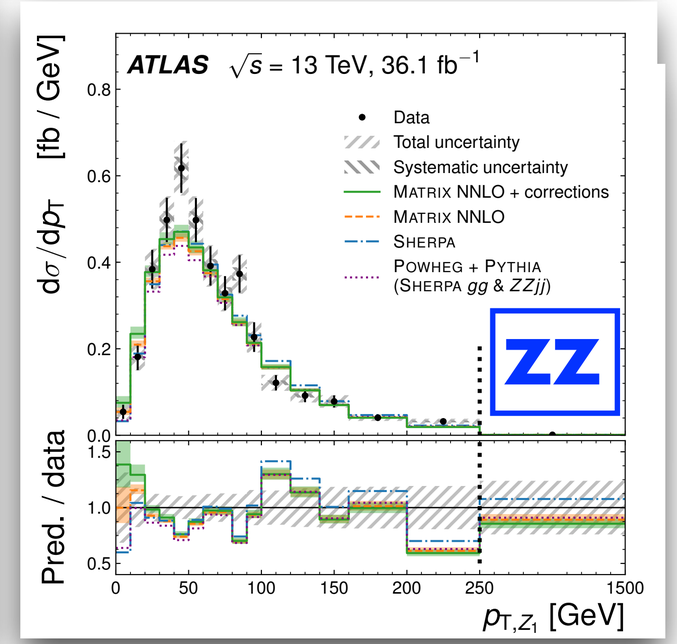

CMS
34.8 fb⁻¹ (13.6 TeV)
Data
POWHEG+PYTHIA
MATRIX
MiNNLO+PYTHIA
Zγ
1/σ dσ/dN_j
Theoretical uncertainty
Theoretical prediction / measurement
POWHEG/Data
MATRIX/Data
MiNNLO/Data
Number of jets


ATLAS
√s=13 TeV, 139 fb⁻¹
Zγ+jets, Z→ll
Data
Sherpa 2.2.4
Sherpa 2.2.11
MG5_aMC+Pythia8
MiNNLO_PS
MATRIX NNLO
Zγ
Prediction/Data
p_T^jet1 [GeV]


137 fb⁻¹ (13 TeV)
CMS
e/μ+jets
Parton level
Data
Syst. ⊕ stat.
Stat.
POWHEG P8 (CP5)
POWHEG H7 (CH3)
MG P8 (CP5)
MATRIX
tt̄
Pred./Data
p_T(t_h) [GeV]


CMS
137 fb⁻¹ (13 TeV)
WZ
Data + stat. unc.
Stat. ⊕ syst. unc.
MATRIX
POWHEG+MCFM+Pyth.
MG5_aMC@NLO+MCFM+Pyth.
Data/Theo
p_T[GeV]


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
pp → e±νμ∓ν
Data 2015+2016
Stat. ⊕ syst. uncertainty
[NNLO(qq)+NLO(gg)]⊗NLO(EW)
Powheg-Box+Pythia8, k=1.13 *
Powheg-Box+Herwig++, k=1.13 *
Sherpa 2.2.2, k=1.0 *
* comb. w. Sherpa+OL gg→WW, k=1.7
WW
Theory / Data
m_eμ [GeV]


ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Data
Total uncertainty
Systematic uncertainty
MATRIX NNLO + corrections
MATRIX NNLO
SHERPA
POWHEG + PYTHIA
(SHERPA gg & ZZjj)
ZZ
dσ/dp_T [fb / GeV]
Pred. / data
p_T,Z1 [GeV]

MATRIX

https://matrix.hepforge.org

[Grazzini, Kallweit, MW '17]

current Matrix extensions

MATRIX+RADISH

https://matrix.hepforge.org/matrix+radish.html

[Kallweit, Re, Rottoli, MW '20]

- ➝ *N³LL resummation for singlet p_T*
- ➝ *NNLL resummation for jet p_T*
- ➝ *NNLL for joint singlet p_T & jet p_T*

MATRIX+PINEAPPL

[Devoto, Kallweit, Schwan 'to appear]

- ➝ *creation of PDF grids for PDF fits*
- ➝ *automatic PDF & α_S variation*

Matrix v1 (fall 2017):

- ➝ *automated NNLO framework*
- ➝ *q_T subtraction*
- ➝ *colour-singlet 2 ➝ 1 and 2 ➝ 2*
- ➝ *publicly available*

Matrix v2 (summer 2021):

- ➝ *gg NLO QCD corrections*
- ➝ *NLO EW corrections*
- ➝ *various QCD-EW combination schemes*
- ➝ *enhance statistics in high-energy tails*

Matrix v2.1 (spring 2023):

- ➝ *included linear power corrections*
- ➝ *added pp ➝ γγγ and pp ➝ tt*
- ➝ *bin-wise r_{cut} extrapolation*
- ➝ *double-differential distributions*

MATRIX

https://matrix.hepforge.org

[Grazzini, Kallweit, MW '17]

current Matrix extensions

MATRIX+RADISH

https://matrix.hepforge.org/matrix+radish.html

[Kallweit, Re, Rottoli, MW '20]

- ➝ *N³LL resummation for singlet p_T*
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- ➝ *NNLL for joint singlet p_T & jet p_T*

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- ➝ *included linear power corrections*
- ➝ *added pp ➝ γγγ and pp ➝ tt*
- ➝ *bin-wise r_{cut} extrapolation*
- ➝ *double-differential distributions*

MATRIX+RadISH framework

[Kallweit, Re, Rottoli, MW '20]

- ***General interface between MATRIX and RadISH codes:***

  all processes available in MATRIX (any color-singlet process possible where 2-loop known)

  high-accuracy multi-differential resummation of various transverse observables

  matching to NNLO QCD integrated cross section

- ***MATRIX*** (v1.1) [Grazzini, Kallweit, MW '17]

  NNLO QCD, phase space, perturbative ingredients (amplitudes, coefficients, ...)

- ***RadISH*** [Monni, Re, and Torrielli '16], [Bizon, Monni, Re, Rottoli, Torrielli '18], [Monni, Rottoli, Torrielli '19]

  resummation formalism in direct space (not in b-space)

  numerical approach (like a semi-inclusive parton shower)

  single-differential resummation [Monni, Re, and Torrielli '16], [Bizon, Monni, Re, Rottoli, Torrielli '18]

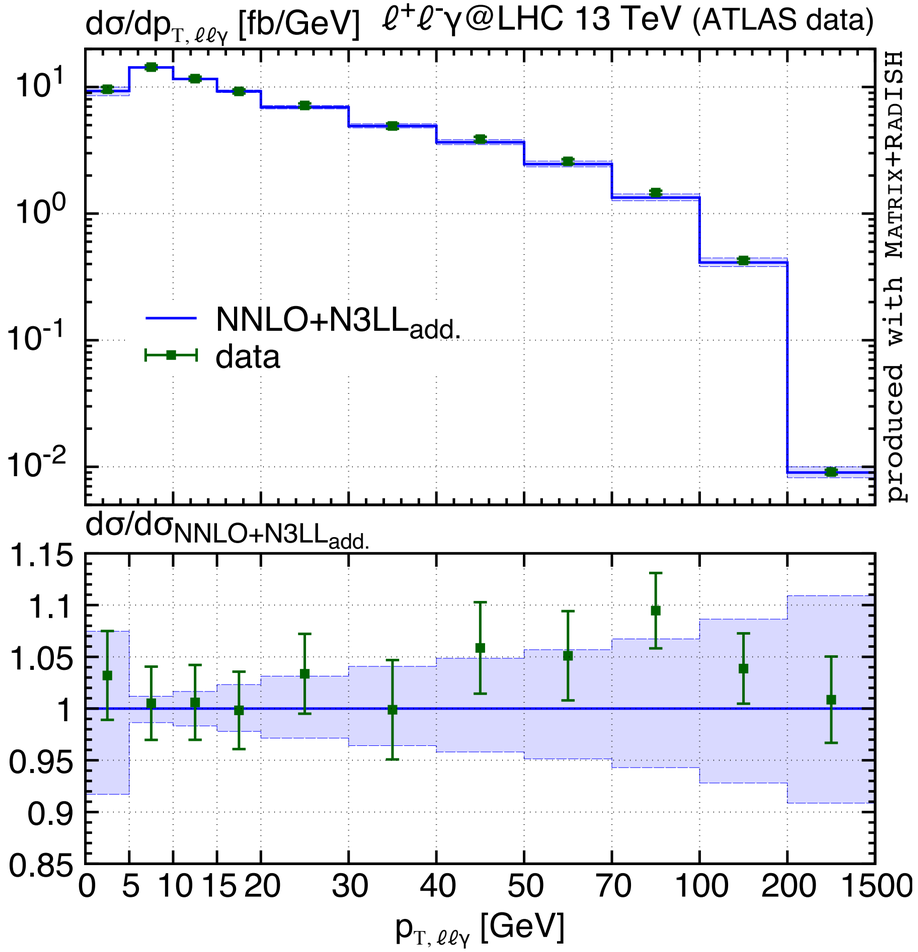
  and double-differential resummation [Monni, Rottoli, Torrielli '19]

click here: `https://matrix.hepforge.org/matrix+radish.html`

MATRIX+RadISH results

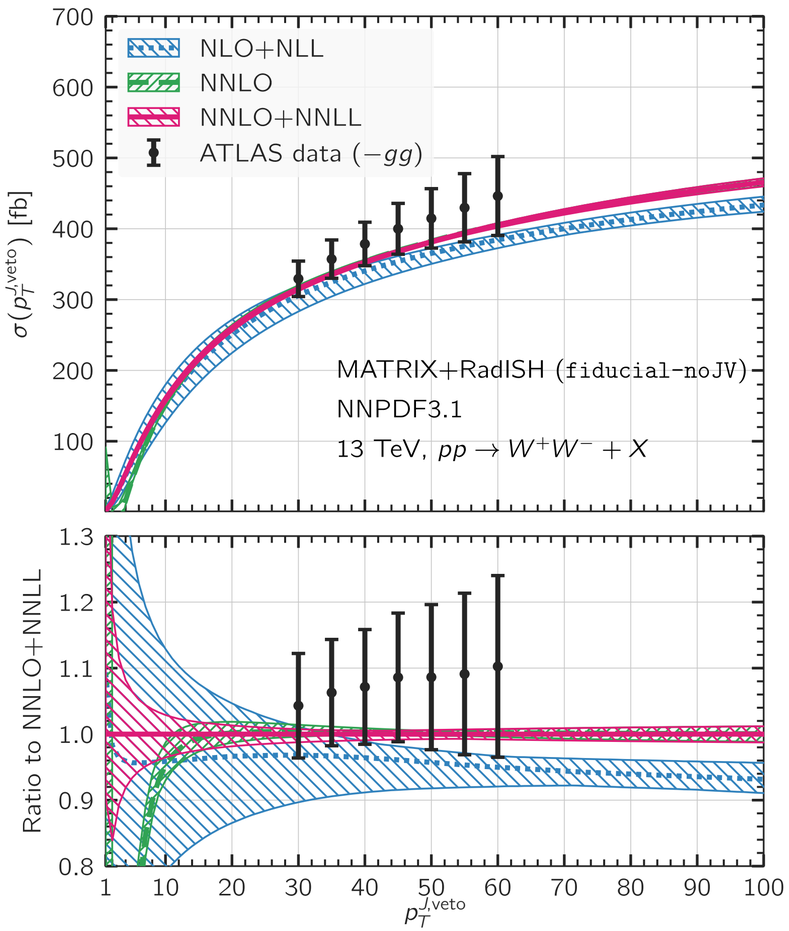
p_T-Zγ@N³LL+NNLO

[MW, Rottoli, Torrielli '20]



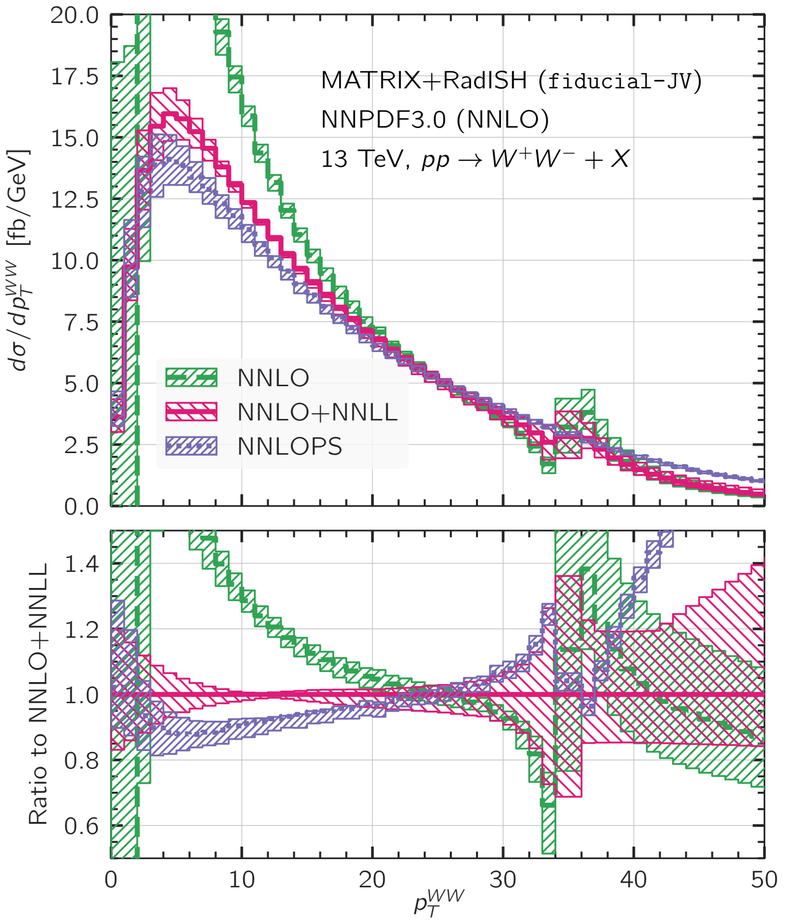
WW jet-veto@NNLL+NNLO

[Kallweit, Re, Rottoli, MW '20]



p_T-WW+jet-veto@NNLL+NNLO

[Kallweit, Re, Rottoli, MW '20]



MATRIX alle Hawaii

[Devoto, Kallweit, Schwan 'to appear]

"Toast Hawaii"

"Pizza Hawaii"

```
$ ./matrix --hawaii
```

$\Rightarrow$ MATRIX + PINEAPPL

...slide borrowed from Stefan Kallweit

MATRIX alle Hawaii

[Devoto, Kallweit, Schwan 'to appear]

- ***General interface between MATRIX and PineAPPL codes:***

  all processes available in MATRIX (implemented in MATRIX main release, v2.1 at the moment)

  creation of NNLO PDF grids that can applied in PDF fits and to do PDF/scale variations

Sample application from LHCHXSWG

Reduced mass and energy scan for $t\bar{t}H$ cross sections:

- NNLO QCD+NLO SM ($\mu_R = \mu_F = m_t + m_H/2$)
- PDF recommendation:

  `PDF4LHC21_40` for partons, `LUXqed17_plus_PDF4LHC15_nnlo_100` for photons

➥ can be straightforwardly achieved through PineAPPL grids, together with scale, PDF and α_s uncertainties

(theory uncertainties calculated directly in Matrix)

$\sqrt{s}$ [TeV]	m_H [GeV]	XS [fb]	± QCD Scale Unc.	± THU	± α_s Unc.	± PDF Unc.
13	124.6	532.0	±3.1%	±0.6%	±1.7%	±2.3%
13	125	528.4	±3.2%	±0.7%	±1.7%	±2.3%
13	125.09	526.6	±3.1%	±0.7%	±1.7%	±2.3%
13	125.38	522.7	±3.1%	±0.7%	±1.7%	±2.3%
13	125.6	519.9	±3.1%	±0.7%	±1.7%	±2.3%
13	126	515.4	±3.1%	±0.7%	±1.7%	±2.3%
13.6	124.6	596.6	±3.0%	±0.7%	±1.6%	±2.2%
13.6	125	589.9	±2.9%	±0.7%	±1.6%	±2.2%
13.6	125.09	589.6	±3.0%	±0.7%	±1.6%	±2.2%
13.6	125.38	586.2	±3.0%	±0.7%	±1.6%	±2.2%
13.6	125.6	583.5	±3.0%	±0.7%	±1.6%	±2.2%
13.6	126	577.9	±3.1%	±0.7%	±1.6%	±2.2%
14	124.6	639.7	±2.9%	±0.7%	±1.6%	±2.2%
14	125	636.1	±3.0%	±0.6%	±1.6%	±2.2%
14	125.09	633.3	±2.9%	±0.6%	±1.6%	±2.2%
14	125.38	632.4	±3.1%	±0.6%	±1.6%	±2.2%
14	125.6	627.9	±3.0%	±0.6%	±1.6%	±2.2%
14	126	621.2	±3.0%	±0.7%	±1.6%	±2.2%

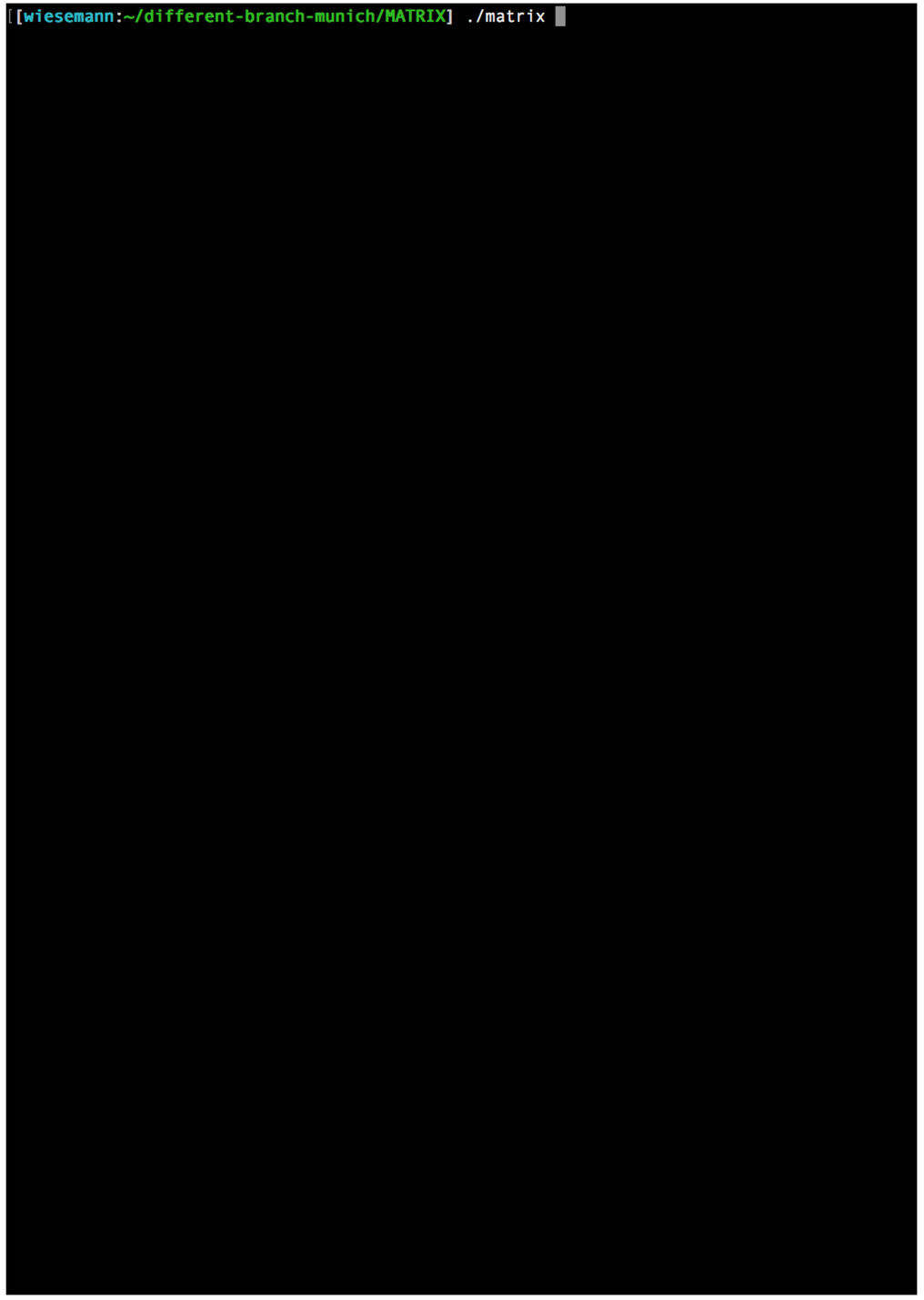
...slide borrowed from Stefan Kallweit

How to compile MATRIX

How to compile

- After unpacking start MATRIX with:

```
$$ ./matrix
```



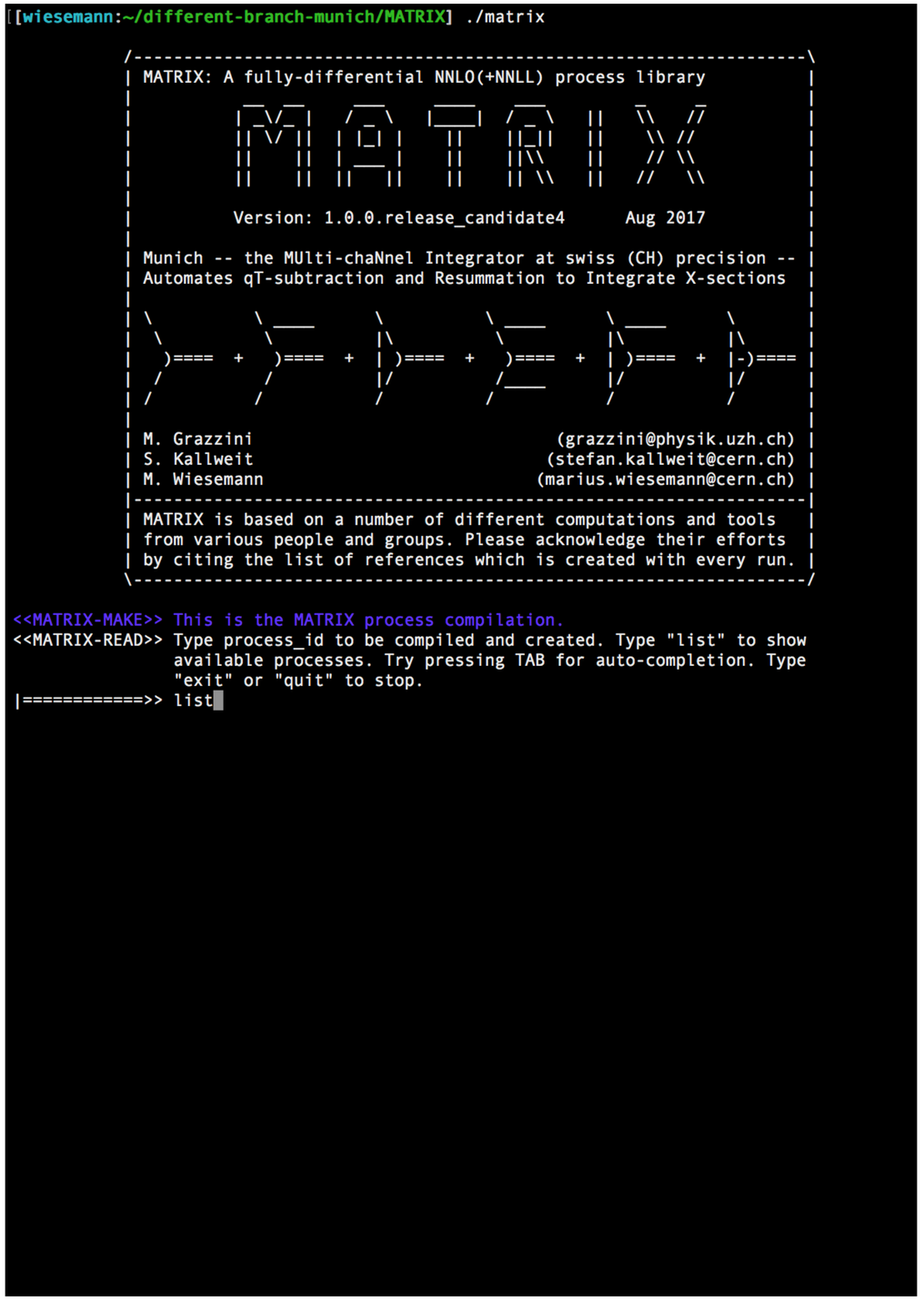
How to compile

- After unpacking start MATRIX with:

```
$$ ./matrix
```

- Inside the MATRIX compilation shell

```
|===>> list
```



How to compile

- After unpacking start MATRIX with:

```
$$ ./matrix
```

- Inside the MATRIX compilation shell

```
|===>> list
```

- lists all process IDs. Select ID, eg:

```
|===>> ppeeexex04
```

```
[[wiesemann:~/different-branch-munich/MATRIX] ./matrix

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
          |                                                                   |
          |          __ __    ___     ____   ___      _     _               |
          |         | _\/_ |  / _ \   |____| / _ \    ||   \\   //          |
          |         || \/ ||  | |_| |    ||   ||_||   ||    \\ //           |
          |         ||    ||  | ___ |    ||   ||\\    ||    // \\           |
          |         ||    ||  ||   ||    ||   || \\   ||   //   \\          |
          |                                                                   |
          |         Version: 1.0.0.release_candidate4      Aug 2017           |
          |                                                                   |
          | Munich -- the MUlti-chaNnel Integrator at swiss (CH) precision -- |
          | Automates qT-subtraction and Resummation to Integrate X-sections  |
          |                                                                   |
          | \          \ ____      \          \ ____      \ ____      \       |
          |  \          \          |\          \          |\          |\      |
          |   )====  +   )====  +  | )====  +   )====  +  | )====  +  |-)==== |
          |  /          /          |/          /____      |/          |/      |
          | /          /           /          /          /          /        |
          |                                                                   |
          | M. Grazzini                              (grazzini@physik.uzh.ch) |
          | S. Kallweit                            (stefan.kallweit@cern.ch)  |
          | M. Wiesemann                          (marius.wiesemann@cern.ch)  |
          |-------------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools   |
          | from various people and groups. Please acknowledge their efforts  |
          | by citing the list of references which is created with every run. |
          \-------------------------------------------------------------------/

<<MATRIX-MAKE>> This is the MATRIX process compilation.
<<MATRIX-READ>> Type process_id to be compiled and created. Type "list" to show
                available processes. Try pressing TAB for auto-completion. Type
                "exit" or "quit" to stop.
[|============>> list
-------------------------------------------------------------------------------------
process_id    ||   process                          ||   description
-------------------------------------------------------------------------------------
pph21         >>   p p --> H                        >>   on-shell Higgs production
ppz01         >>   p p --> Z                        >>   on-shell Z production
ppw01         >>   p p --> W^-                      >>   on-shell W- production with CKM
ppwx01        >>   p p --> W^+                      >>   on-shell W+ production with CKM
ppeex02       >>   p p --> e^- e^+                  >>   Z production with decay
ppnenex02     >>   p p --> v_e^- v_e^+              >>   Z production with decay
ppenex02      >>   p p --> e^- v_e^+                >>   W- production with decay and CKM
ppexne02      >>   p p --> e^+ v_e^-                >>   W+ production with decay and CKM
ppaa02        >>   p p --> gamma gamma              >>   gamma gamma production
ppeexa03      >>   p p --> e^- e^+ gamma            >>   Z gamma production with decay
ppnenexa03    >>   p p --> v_e^- v_e^+ gamma        >>   Z gamma production with decay
ppenexa03     >>   p p --> e^- v_e^+ gamma          >>   W- gamma production with decay
ppexnea03     >>   p p --> e^+ v_e^- gamma          >>   W+ gamma production with decay
ppzz02        >>   p p --> Z Z                      >>   on-shell ZZ production
ppwxw02       >>   p p --> W^+ W^-                  >>   on-shell WW production
ppemexmx04    >>   p p --> e^- mu^- e^+ mu^+        >>   ZZ production with decay
ppeeexex04    >>   p p --> e^- e^- e^+ e^+          >>   ZZ production with decay
ppeexnmnmx04  >>   p p --> e^- e^+ v_mu^- v_mu^+    >>   ZZ production with decay
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+    >>   WW production with decay
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+      >>   ZZ/WW production with decay
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+      >>   W-Z production with decay
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+        >>   W-Z production with decay
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-      >>   W+Z production with decay
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-        >>   W+Z production with decay
[|============>> ppeeexex04
```

How to compile

- After unpacking start MATRIX with:

```
$$ ./matrix
```

- Inside the MATRIX compilation shell

```
|===>> list
```

- lists all process IDs. Select ID, eg:

```
|===>> ppeeexex04
```

- for pp→ZZ→4ℓ. Confirming with

```
|===>> y
```

```
          | M. Wiesemann                          (marius.wiesemann@cern.ch) |
          |-----------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools |
          | from various people and groups. Please acknowledge their efforts |
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          \-----------------------------------------------------------------/

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-------------------------------------------------------------------------------------------
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-------------------------------------------------------------------------------------------
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ppw01         >>   p p --> W^-                      >>   on-shell W- production with CKM
ppwx01        >>   p p --> W^+                      >>   on-shell W+ production with CKM
ppeex02       >>   p p --> e^- e^+                  >>   Z production with decay
ppnenex02     >>   p p --> v_e^- v_e^+              >>   Z production with decay
ppenex02      >>   p p --> e^- v_e^+                >>   W- production with decay and CKM
ppexne02      >>   p p --> e^+ v_e^-                >>   W+ production with decay and CKM
ppaa02        >>   p p --> gamma gamma              >>   gamma gamma production
ppeexa03      >>   p p --> e^- e^+ gamma            >>   Z gamma production with decay
ppnenexa03    >>   p p --> v_e^- v_e^+ gamma        >>   Z gamma production with decay
ppenexa03     >>   p p --> e^- v_e^+ gamma          >>   W- gamma production with decay
ppexnea03     >>   p p --> e^+ v_e^- gamma          >>   W+ gamma production with decay
ppzz02        >>   p p --> Z Z                      >>   on-shell ZZ production
ppwxw02       >>   p p --> W^+ W^-                  >>   on-shell WW production
ppemexmx04    >>   p p --> e^- mu^- e^+ mu^+        >>   ZZ production with decay
ppeeexex04    >>   p p --> e^- e^- e^+ e^+          >>   ZZ production with decay
ppeexnmnmx04  >>   p p --> e^- e^+ v_mu^- v_mu^+    >>   ZZ production with decay
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+    >>   WW production with decay
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+      >>   ZZ/WW production with decay
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+      >>   W-Z production with decay
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+        >>   W-Z production with decay
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-      >>   W+Z production with decay
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-        >>   W+Z production with decay
[|============>> ppeeexex04
<<MATRIX-MAKE>> MATRIX usage agreements:
<<MATRIX-MAKE>> MATRIX is based on several computations, studies and tools from
                various people and groups. When using results obtained by MATRIX
                these efforts must be acknowledged by citing the list of
                references in the CITATION.bib file, which is created in the
                result folder with every run.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code OpenLoops from
                http://openloops.hepforge.org. You have to cite arXiv:1111.5206
                from F. Cascioli, P. Maierhoefer, S. Pozzorini, when using
                results obtained with this installation.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code VVamp from
                http://vvamp.hepforge.org. You have to cite arXiv:1503.04812
                from T. Gehrmann, A. von Manteuffel, L. Tancredi, when using
                results obtained with this installation.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
 |============>> y
```

How to compile

- After unpacking start MATRIX with:

```
$$ ./matrix
```

- Inside the MATRIX compilation shell

```
|===>> list
```

- lists all process IDs. Select ID, eg:

```
|===>> ppeeexex04
```

- for pp→ZZ→4ℓ. Confirming with

```
|===>> y
```

- the MATRIX usage agreements, the code will automatically start to:
  - dowload/compile of OpenLoops
  - compile of Cln and Ginac
  - compile MATRIX
  - download OpenLoops amplitudes
  - create MATRIX run folder for the process

```
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+   >>   WW production with decay
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+     >>   ZZ/WW production with decay
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+     >>   W-Z production with decay
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+       >>   W-Z production with decay
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-     >>   W+Z production with decay
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-       >>   W+Z production with decay
[|============>> ppeeexex04
<<MATRIX-MAKE>> MATRIX usage agreements:
<<MATRIX-MAKE>> MATRIX is based on several computations, studies and tools from
                various people and groups. When using results obtained by MATRIX
                these efforts must be acknowledged by citing the list of
                references in the CITATION.bib file, which is created in the
                result folder with every run.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code OpenLoops from
                http://openloops.hepforge.org. You have to cite arXiv:1111.5206
                from F. Cascioli, P. Maierhoefer, S. Pozzorini, when using
                results obtained with this installation.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code VVamp from
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                from T. Gehrmann, A. von Manteuffel, L. Tancredi, when using
                results obtained with this installation.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> You have agreed with all MATRIX usage terms.
<<MATRIX-MAKE>> Starting compilation...
<<MATRIX-MAKE>> Using compiled LHAPDF installation under
                (config/MATRIX_configuration)
                path_to_lhapdf=/mnt/shared/lhapdf_install/bin/lhapdf-config
<<MATRIX-MAKE>> OpenLoops already downloaded and compiled. Remove folder
                /home/wiesemann/different-branch-munich/MATRIX/src-external
                /OpenLoops-install if you want to re-download and re-compile...
<<MATRIX-MAKE>> Cln already compiled. Remove folder /home/wiesemann/different-
                branch-munich/MATRIX/src-external/cln-install if you want to re-
                compile...
<<MATRIX-MAKE>> Ginac already compiled. Remove folder /home/wiesemann/different-
                branch-munich/MATRIX/src-external/ginac-install if you want to
                re-compile...
<<MATRIX-MAKE>> Compiling process <ppeeexex04>, this may take a while...
                (see make.log file to monitor the progress)
<<MATRIX-MAKE>> OpenLoops pplll amplitude already downloaded and compiled.
                Checking wether up-to-date...
<<MATRIX-MAKE>> ...pplll amplitude already installed and up-to-date.
<<MATRIX-MAKE>> OpenLoops ppllllj amplitude already downloaded and compiled.
                Checking wether up-to-date...
<<MATRIX-MAKE>> ...ppllllj amplitude already installed and up-to-date.
<<MATRIX-MAKE>> OpenLoops pllll2 amplitude already downloaded and compiled.
                Checking wether up-to-date...
<<MATRIX-MAKE>> ...pllll2 amplitude updated.
<<MATRIX-MAKE>> Creating process folder in "run"-directory: "/home/wiesemann
                /different-branch-munich/MATRIX/run/ppeeexex04_MATRIX"...
<<MATRIX-INFO>> Process folder successfully created.
<<MATRIX-INFO>> Process generation finished, to go to the run directory type:
                cd /home/wiesemann/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX
<<MATRIX-INFO>> and start run by typing:
                ./bin/run_process
[wiesemann:~/different-branch-munich/MATRIX]
```

Hands on !

- download PDF of this session!
- two options:

1. use your own laptop locally

   ➙ need to install LHAPDF from https://lhapdf.hepforge.org/ (including the needed PDF set)

2. use your remote ssh login (for Mac/Windoof users highly recommended)

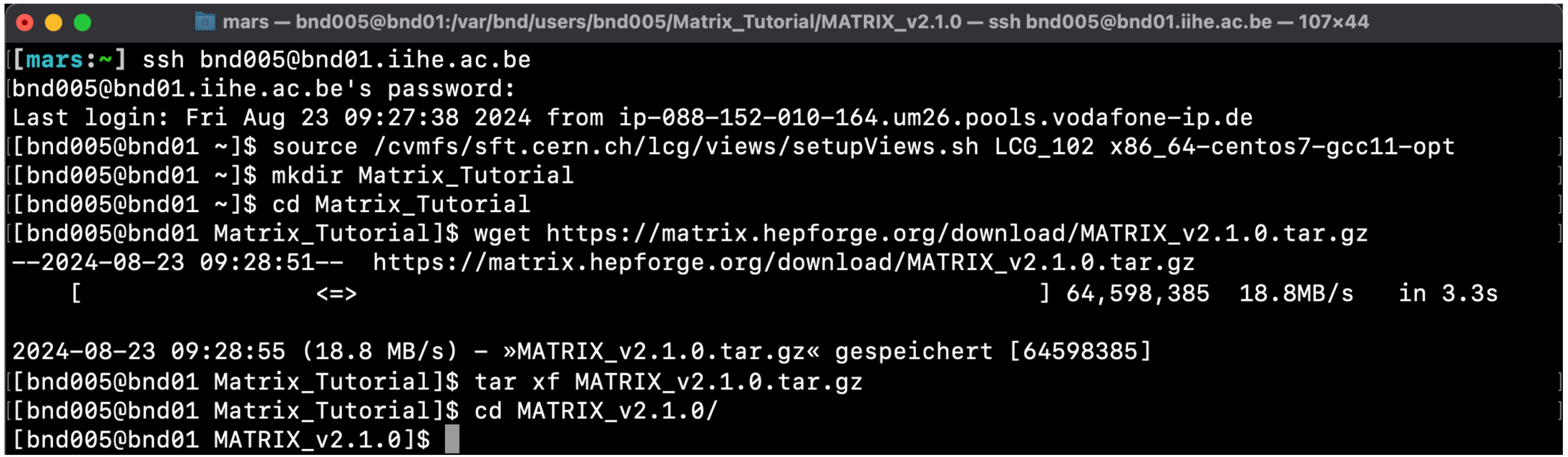
   `$ ssh bndXXX@bnd01.iihe.ac.be` ➙ enter password

   `($ source /cvmfs/sft.cern.ch/lcg/views/setupViews.sh LCG_102 x86_64-centos7-gcc11-opt` ➙ should not be needed, check: **`gcc --version`** ➙ 11.2.0)

Hands on !

- download & setup MATRIX from https://matrix.hepforge.org/

```
$ mkdir Matrix_tutorial
$ cd Matrix_tutorial
$ wget https://matrix.hepforge.org/download/MATRIX_v2.1.0.tar.gz
$ tar xf MATRIX_v2.1.0.tar.gz
$ cd MATRIX_v2.1.0/
```



Hands on !

- start compilation script

```
$ ./matrix
```

task: check list of processes using the script and find short-cut for charge neutral Drell-Yan without decay

answer?

Hands on !

- start compilation script

```
$ ./matrix
```

task: check list of processes using the script and find short-cut for charge neutral Drell-Yan without decay

answer: the short cut for on-shell Z-boson production is **ppz01**

Hands on !

- start compilation script

  `$ ./matrix`

  `>>> list` (or just ENTER)

Hands on !

- start compilation script

  `$ ./matrix`

  `>>> list` (or just ENTER)

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0 — ssh bnd005@bnd01.iihe.ac.be — 107×44
          | M. Grazzini                              (grazzini@physik.uzh.ch) |
          | S. Kallweit                             (stefan.kallweit@cern.ch) |
          | M. Wiesemann                           (marius.wiesemann@cern.ch) |
          |-----------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools  |
          | from various people and groups. Please acknowledge their efforts |
          | by citing the references in CITATIONS.bib created with every run. |
          \-----------------------------------------------------------------/

<<MATRIX-MAKE>> This is the MATRIX process compilation.
<<MATRIX-READ>> Type process_id to be compiled and created. Type "list" to show
                available processes. Try pressing TAB for auto-completion. Type
                "exit" or "quit" to stop.
|============>> list
-------------------------------------------------------------------------------------------------------------
process_id    ||   process                          ||   description
-------------------------------------------------------------------------------------------------------------
pph21         >>   p p --> H                        >>   on-shell Higgs production (NNLO)
ppz01         >>   p p --> Z                        >>   on-shell Z production (NNLO,NLO EW)
ppw01         >>   p p --> W^-                      >>   on-shell W- production with CKM (NNLO)
ppwx01        >>   p p --> W^+                      >>   on-shell W+ production with CKM (NNLO)
ppeex02       >>   p p --> e^- e^+                  >>   Z production with decay (NNLO,NLO EW)
ppnenex02     >>   p p --> v_e^- v_e^+              >>   Z production with decay (NNLO,NLO EW)
ppenex02      >>   p p --> e^- v_e^+                >>   W- production with decay and CKM (NNLO,NLO EW)
ppexne02      >>   p p --> e^+ v_e^-                >>   W+ production with decay and CKM (NNLO,NLO EW)
ppaa02        >>   p p --> gamma gamma              >>   gamma gamma production (NNLO)
ppeexa03      >>   p p --> e^- e^+ gamma            >>   Z gamma production with decay (NNLO)
ppnenexa03    >>   p p --> v_e^- v_e^+ gamma        >>   Z gamma production with decay (NNLO)
ppenexa03     >>   p p --> e^- v_e^+ gamma          >>   W- gamma production with decay (NNLO)
ppexnea03     >>   p p --> e^+ v_e^- gamma          >>   W+ gamma production with decay (NNLO)
ppzz02        >>   p p --> Z Z                      >>   on-shell ZZ production (NNLO)
ppwxw02       >>   p p --> W^+ W^-                  >>   on-shell WW production (NNLO)
ppemexmx04    >>   p p --> e^- mu^- e^+ mu^+        >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeeexex04    >>   p p --> e^- e^- e^+ e^+          >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeexnmnmx04  >>   p p --> e^- e^+ v_mu^- v_mu^+    >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+    >>   WW production with decay (NNLO,NLO gg,NLO EW)
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+      >>   ZZ/WW production with decay (NNLO,NLO gg,NLO EW)
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+      >>   W-Z production with decay (NNLO,NLO EW)
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+        >>   W-Z production with decay (NNLO,NLO EW)
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-      >>   W+Z production with decay (NNLO,NLO EW)
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-        >>   W+Z production with decay (NNLO,NLO EW)
ppttx20       >>   p p --> top anti-top             >>   on-shell top-pair production (NNLO)
ppaaa03       >>   p p --> gamma gamma gamma        >>   gamma gamma gamma production (NNLO)
|============>>
```

Hands on !

- start compilation script

  `$ ./matrix`

  `>>> list` (or just ENTER)

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0 — ssh bnd005@bnd01.iihe.ac.be — 107×44
          | M. Grazzini                                (grazzini@physik.uzh.ch) |
          | S. Kallweit                               (stefan.kallweit@cern.ch) |
          | M. Wiesemann                             (marius.wiesemann@cern.ch) |
          |-------------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools   |
          | from various people and groups. Please acknowledge their efforts  |
          | by citing the references in CITATIONS.bib created with every run. |
          \-------------------------------------------------------------------/

<<MATRIX-MAKE>> This is the MATRIX process compilation.
<<MATRIX-READ>> Type process_id to be compiled and created. Type "list" to show
                available processes. Try pressing TAB for auto-completion. Type
                "exit" or "quit" to stop.
|============>> list
-------------------------------------------------------------------------------------------------------------------
process_id    ||   process                          ||   description
-------------------------------------------------------------------------------------------------------------------
pph21         >>   p p --> H                        >>   on-shell Higgs production (NNLO)
ppz01         >>   p p --> Z                        >>   on-shell Z production (NNLO,NLO EW)
ppw01         >>   p p --> W^-                      >>   on-shell W- production with CKM (NNLO)
ppwx01        >>   p p --> W^+                      >>   on-shell W+ production with CKM (NNLO)
ppeex02       >>   p p --> e^- e^+                  >>   Z production with decay (NNLO,NLO EW)
ppnenex02     >>   p p --> v_e^- v_e^+              >>   Z production with decay (NNLO,NLO EW)
ppenex02      >>   p p --> e^- v_e^+                >>   W- production with decay and CKM (NNLO,NLO EW)
ppexne02      >>   p p --> e^+ v_e^-                >>   W+ production with decay and CKM (NNLO,NLO EW)
ppaa02        >>   p p --> gamma gamma              >>   gamma gamma production (NNLO)
ppeexa03      >>   p p --> e^- e^+ gamma            >>   Z gamma production with decay (NNLO)
ppnenexa03    >>   p p --> v_e^- v_e^+ gamma        >>   Z gamma production with decay (NNLO)
ppenexa03     >>   p p --> e^- v_e^+ gamma          >>   W- gamma production with decay (NNLO)
ppexnea03     >>   p p --> e^+ v_e^- gamma          >>   W+ gamma production with decay (NNLO)
ppzz02        >>   p p --> Z Z                      >>   on-shell ZZ production (NNLO)
ppwxw02       >>   p p --> W^+ W^-                  >>   on-shell WW production (NNLO)
ppemexmx04    >>   p p --> e^- mu^- e^+ mu^+        >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeeexex04    >>   p p --> e^- e^- e^+ e^+          >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeexnmnmx04  >>   p p --> e^- e^+ v_mu^- v_mu^+    >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+    >>   WW production with decay (NNLO,NLO gg,NLO EW)
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+      >>   ZZ/WW production with decay (NNLO,NLO gg,NLO EW)
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+      >>   W-Z production with decay (NNLO,NLO EW)
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+        >>   W-Z production with decay (NNLO,NLO EW)
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-      >>   W+Z production with decay (NNLO,NLO EW)
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-        >>   W+Z production with decay (NNLO,NLO EW)
ppttx20       >>   p p --> top anti-top             >>   on-shell top-pair production (NNLO)
ppaaa03       >>   p p --> gamma gamma gamma        >>   gamma gamma gamma production (NNLO)
|============>>
```

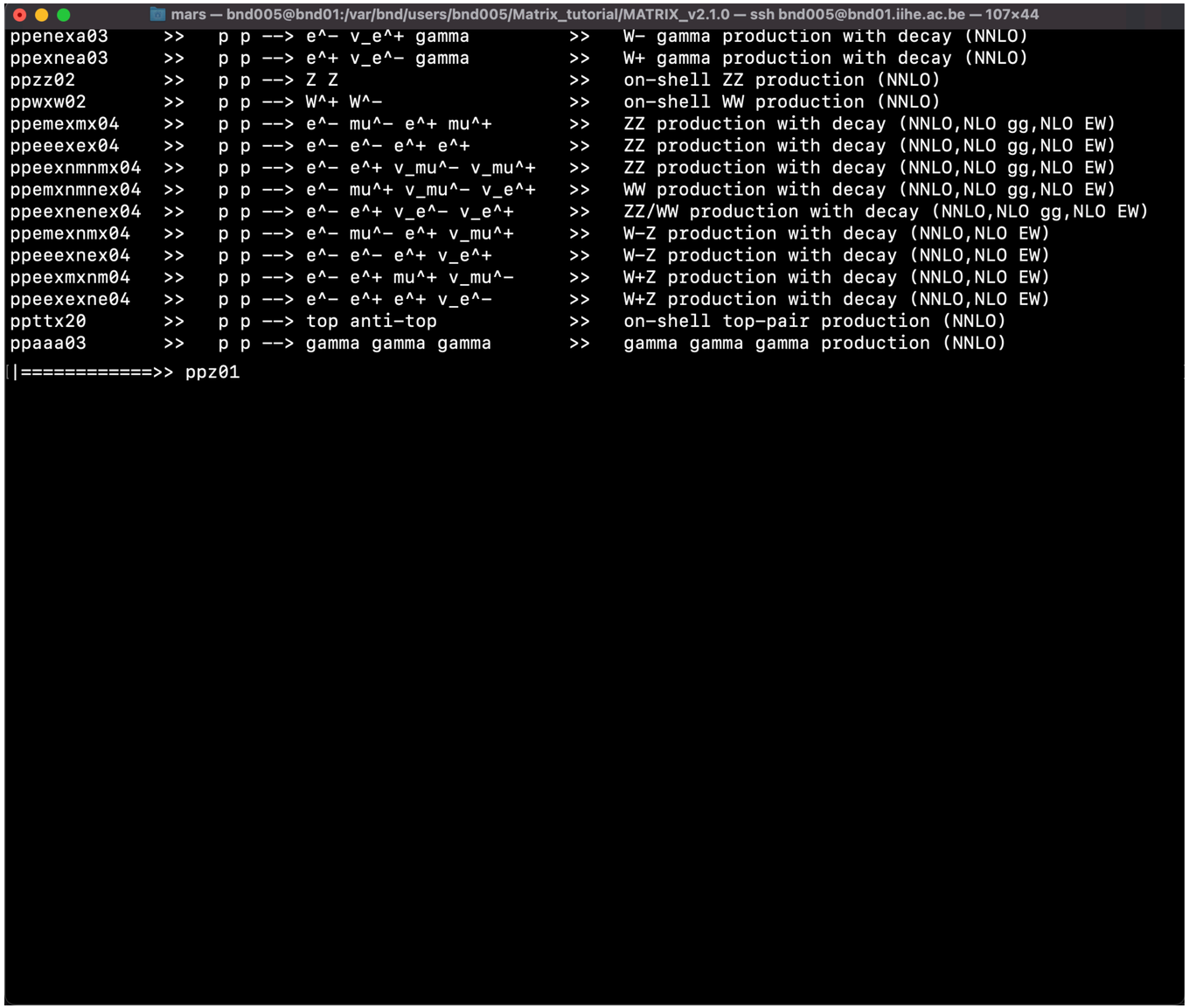
Hands on !

- start compilation script

```
$ ./matrix
```

```
>>> list  (or just ENTER)
```

```
>>> ppz01
```



Hands on !

- start compilation script

```
$ ./matrix
>>> list  (or just ENTER)
>>> ppz01
>>> y...y...
```

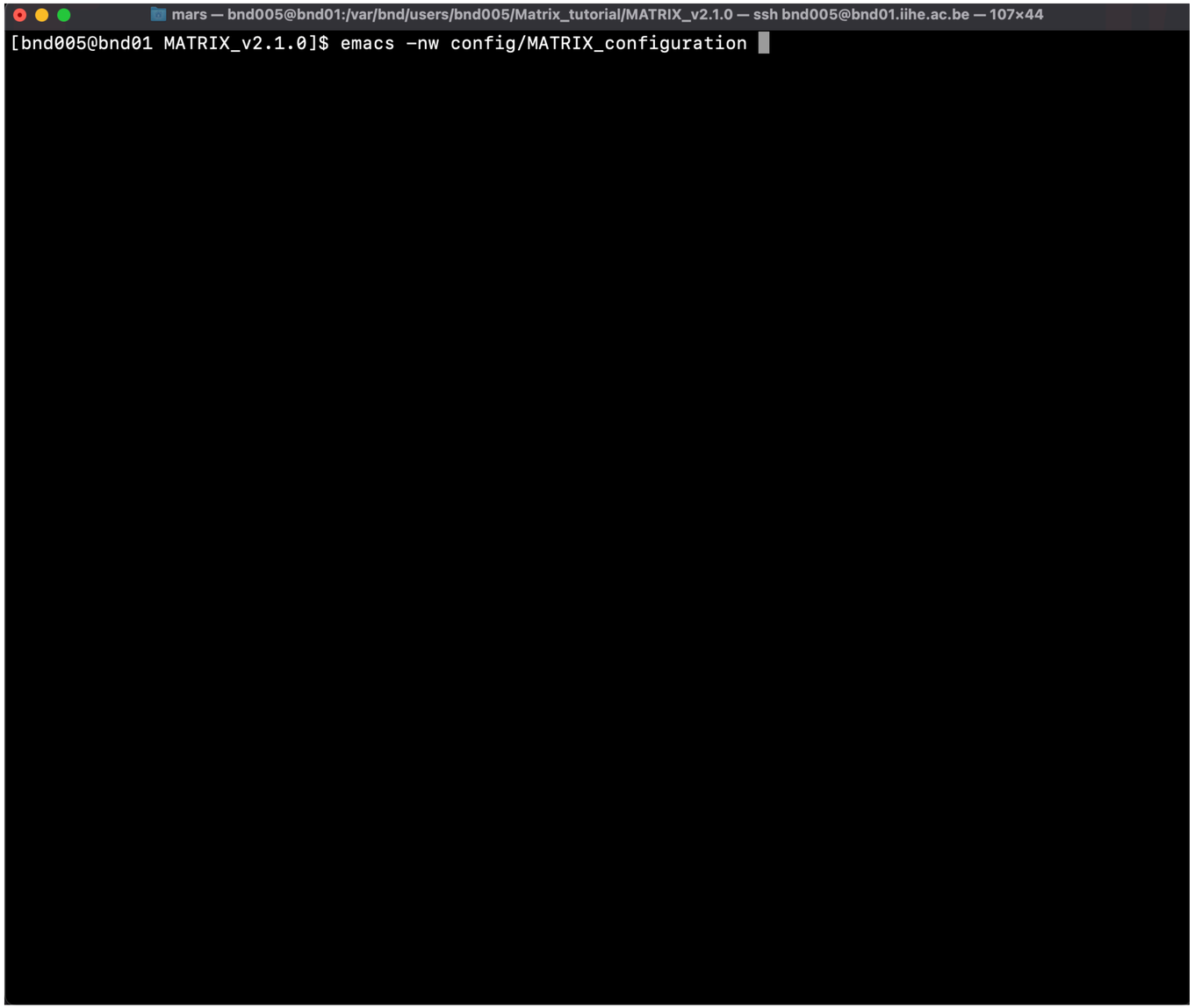
LHAPDF missing !

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0 — ssh bnd005@bnd01.iihe.ac.be — 107×44
ppenexa03     >>   p p --> e^- v_e^+ gamma          >>   W- gamma production with decay (NNLO)
ppexnea03     >>   p p --> e^+ v_e^- gamma          >>   W+ gamma production with decay (NNLO)
ppzz02        >>   p p --> Z Z                      >>   on-shell ZZ production (NNLO)
ppwxw02       >>   p p --> W^+ W^-                  >>   on-shell WW production (NNLO)
ppemexmx04    >>   p p --> e^- mu^- e^+ mu^+        >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeeexex04    >>   p p --> e^- e^- e^+ e^+          >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppeexnmnmx04  >>   p p --> e^- e^+ v_mu^- v_mu^+    >>   ZZ production with decay (NNLO,NLO gg,NLO EW)
ppemxnmnex04  >>   p p --> e^- mu^+ v_mu^- v_e^+    >>   WW production with decay (NNLO,NLO gg,NLO EW)
ppeexnenex04  >>   p p --> e^- e^+ v_e^- v_e^+      >>   ZZ/WW production with decay (NNLO,NLO gg,NLO EW)
ppemexnmx04   >>   p p --> e^- mu^- e^+ v_mu^+      >>   W-Z production with decay (NNLO,NLO EW)
ppeeexnex04   >>   p p --> e^- e^- e^+ v_e^+        >>   W-Z production with decay (NNLO,NLO EW)
ppeexmxnm04   >>   p p --> e^- e^+ mu^+ v_mu^-      >>   W+Z production with decay (NNLO,NLO EW)
ppeexexne04   >>   p p --> e^- e^+ e^+ v_e^-        >>   W+Z production with decay (NNLO,NLO EW)
ppttx20       >>   p p --> top anti-top             >>   on-shell top-pair production (NNLO)
ppaaa03       >>   p p --> gamma gamma gamma        >>   gamma gamma gamma production (NNLO)
[|============>> ppz01
<<MATRIX-MAKE>> MATRIX usage agreements:
<<MATRIX-MAKE>> MATRIX is based on several computations, studies and tools from
                various people and groups. When using results obtained by MATRIX
                these efforts must be acknowledged by citing the list of
                references in the CITATION.bib file, which is created in the
                result folder with every run.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code OpenLoops from
                http://openloops.hepforge.org by F. Buccioni, F. Cascioli, J.-N.
                Lang, J. Lindert, P. Maierhoefer, S. Pozzorini, H. Zhang, M.
                Zoller. You have to cite the relavant references in
                CITATIONS.bib, when using results obtained with this
                installation.
<<MATRIX-READ>> Do you agree with these terms? Type "y" to agree, or "n" to
                abort the code.
[|============>> y
<<MATRIX-MAKE>> You have agreed with all MATRIX usage terms.
<<MATRIX-MAKE>> Creating input files for process ppz01 inside folder /var/bnd/us
                ers/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/input_files/ppz01..
                .
<<MATRIX-MAKE>> Starting compilation...
<<MATRIX-ERROR>> No installation of LHAPDF found. Install LHAPDF such that
                 lhapdf-config executable is found under your environmental
                 $PATH variable or specify path to lhapdf-config under
                 "path_to_lhapdf" in MATRIX_configuration file.
[bnd005@bnd01 MATRIX_v2.1.0]$
```

Hands on !

- open MATRIX_configuration file and add path to LHAPDF (or **`lhapdf_config`** has to recognized/in **`$PATH`** variable)

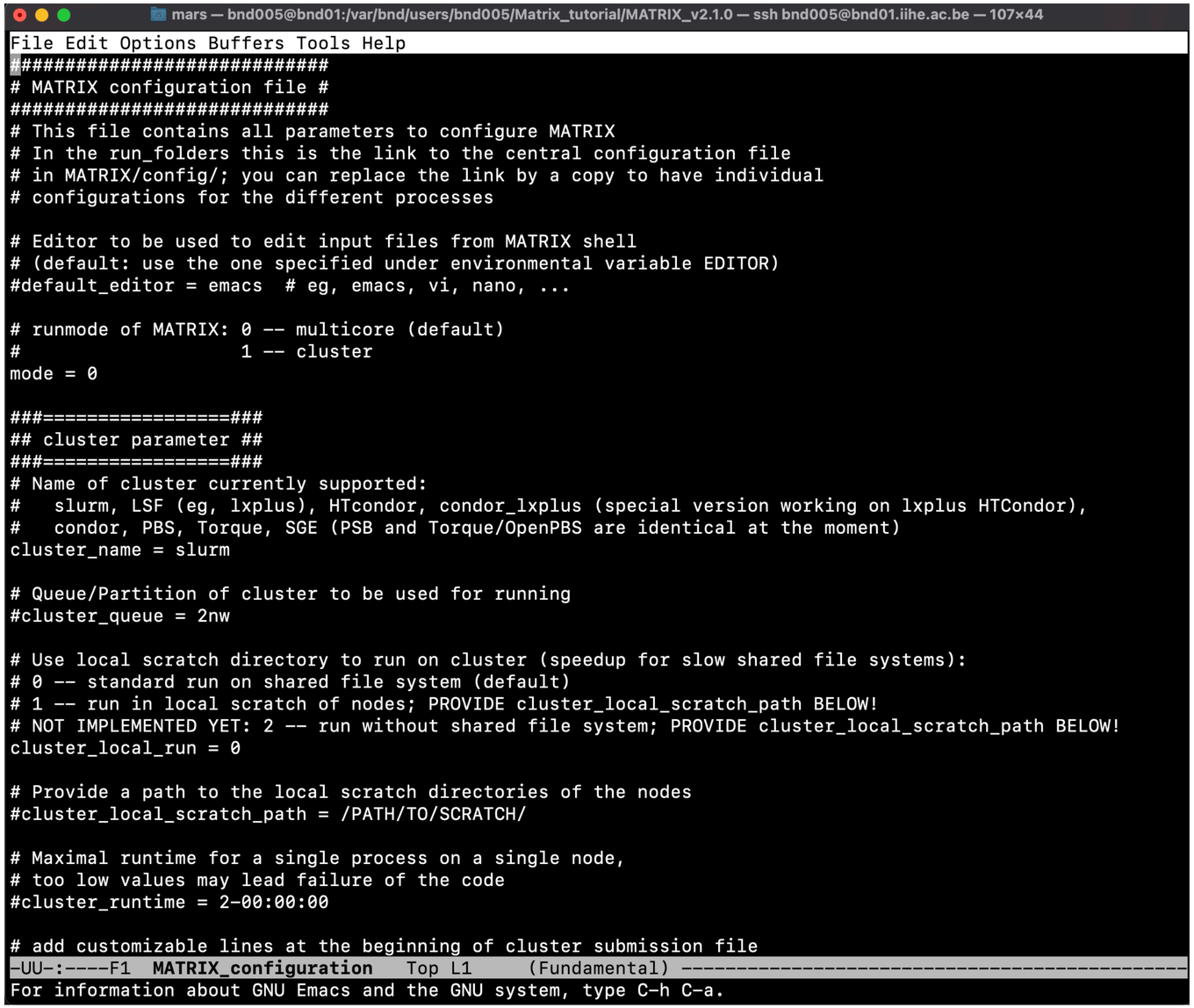
```
$ emacs -nw config/
MATRIX_configuration
```



Hands on !

- open MATRIX_configuration file and add path to LHAPDF (or **`lhapdf_config`** has to recognized/in **`$PATH`** variable)

`$ emacs -nw config/MATRIX_configuration`

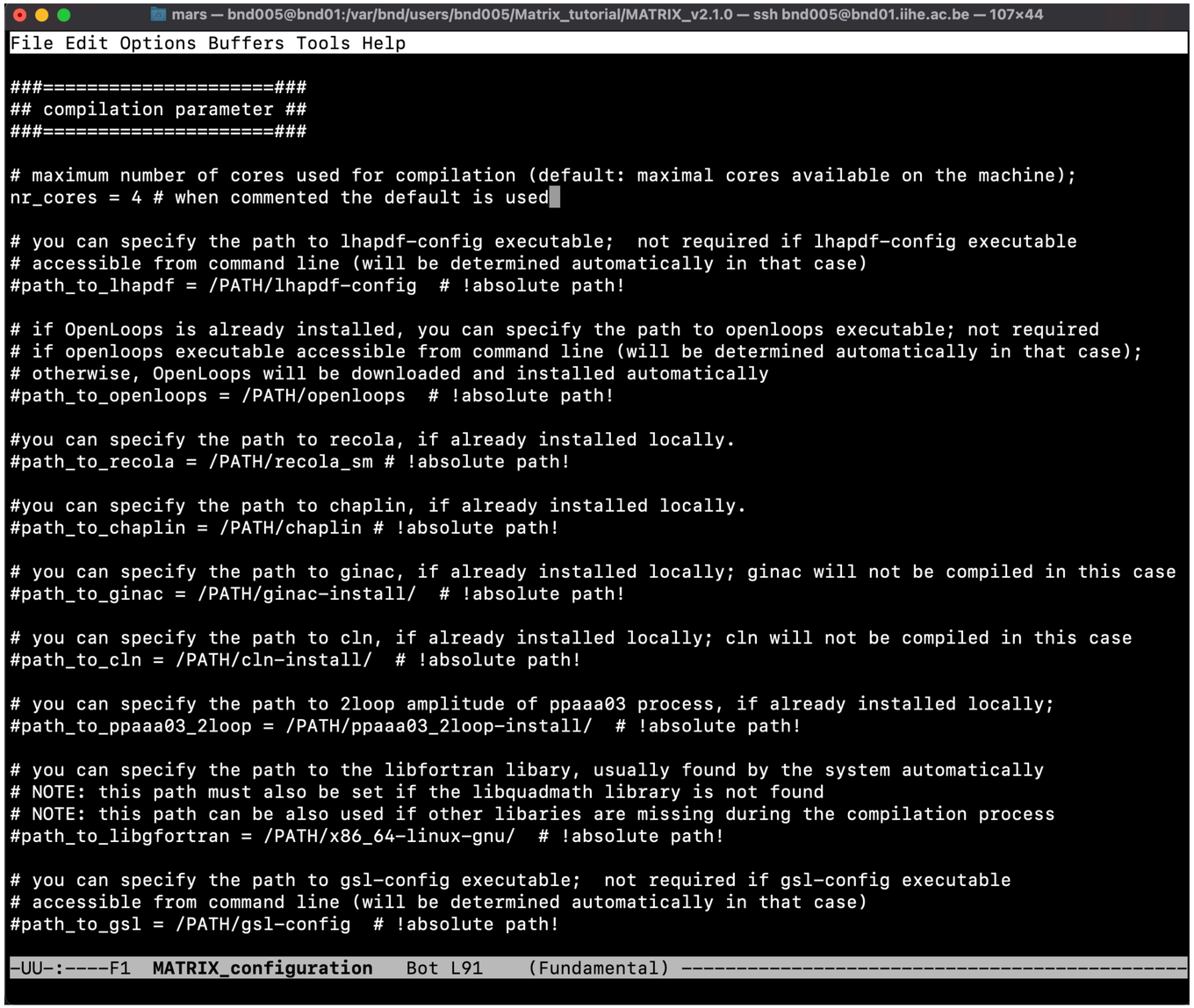


Hands on !

- open MATRIX_configuration file and add path to LHAPDF (or **`lhapdf_config`** has to recognized/in **`$PATH`** variable)

  `$ emacs -nw config/MATRIX_configuration`

  `> Ctrl-v` (or arrows to scroll down)



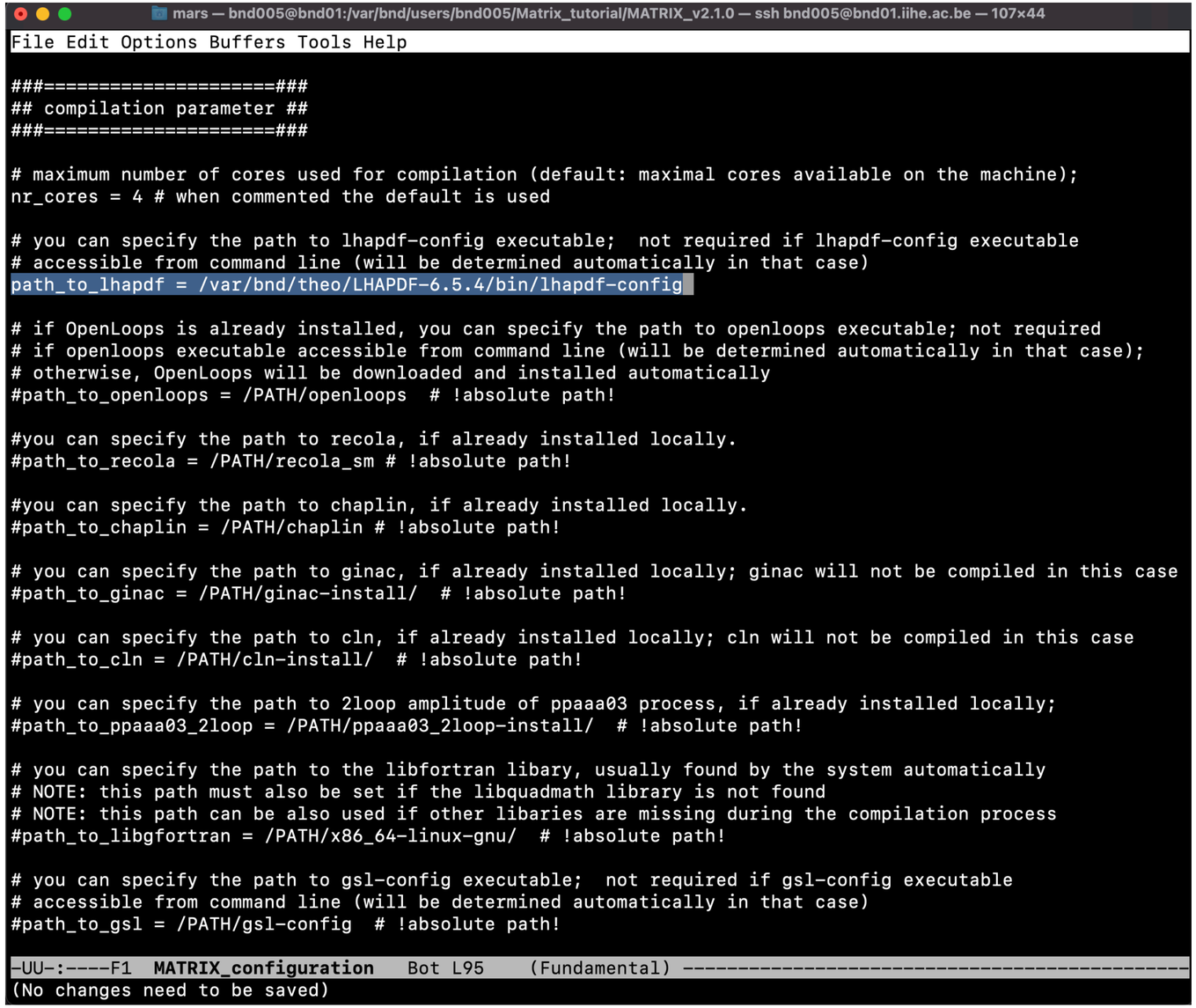
Hands on !

- open MATRIX_configuration file and add path to LHAPDF (or **`lhapdf-config`** has to recognized/in **`$PATH`** variable)

`$ emacs -nw config/MATRIX_configuration`

`> Ctrl-v` (or arrows to scroll down)

`> path_to_lhapdf = /var/bnd/theo/LHAPDF-6.5.4/bin/lhapdf-config` (set)



Hands on !

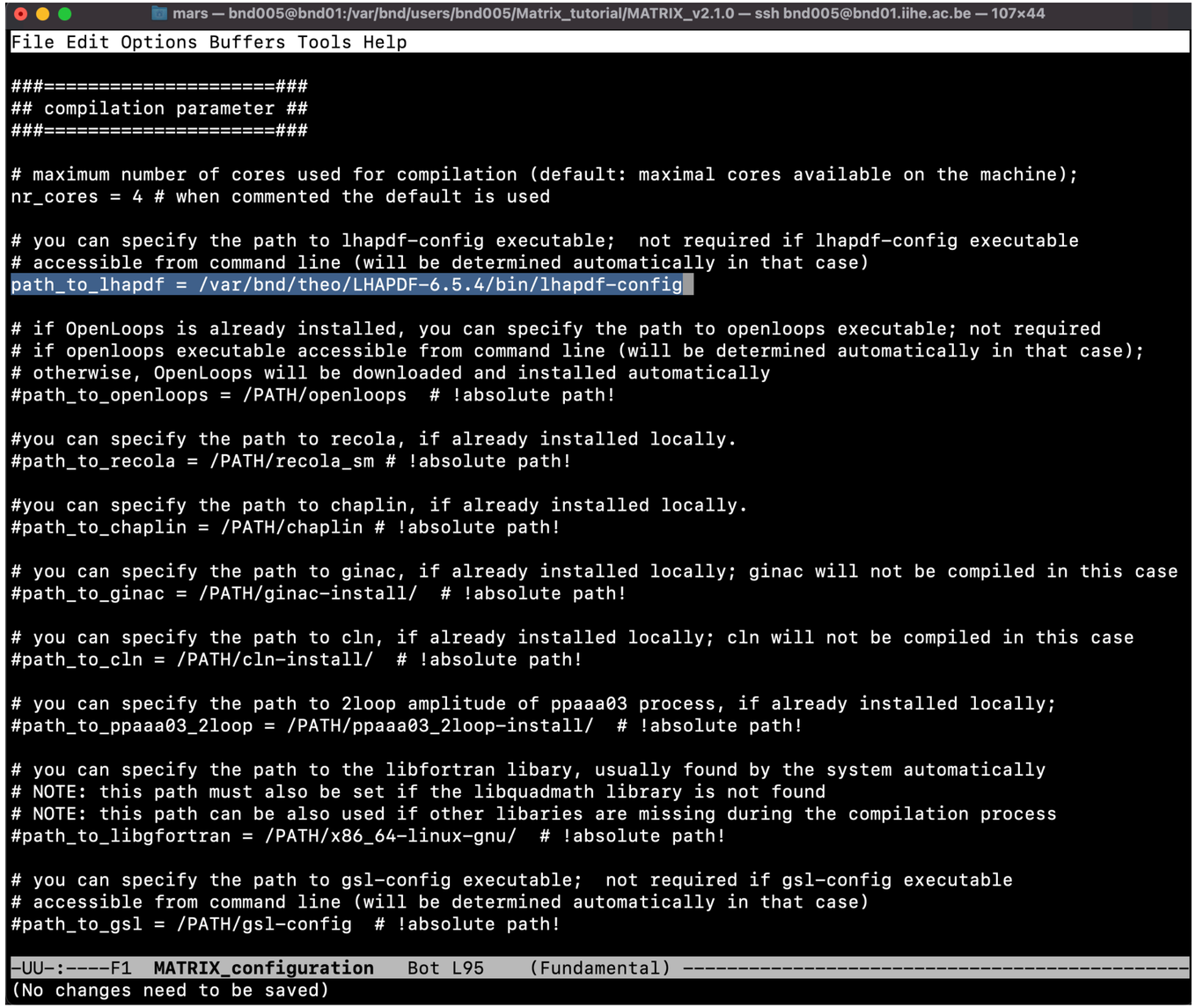
- open MATRIX_configuration file and add path to LHAPDF (or **`lhapdf-config`** has to recognized/in **`$PATH`** variable)

`$ emacs -nw config/MATRIX_configuration`

`> Ctrl-v` (or arrows to scroll down)

`> path_to_lhapdf = /var/bnd/theo/LHAPDF-6.5.4/bin/lhapdf-config` (set)

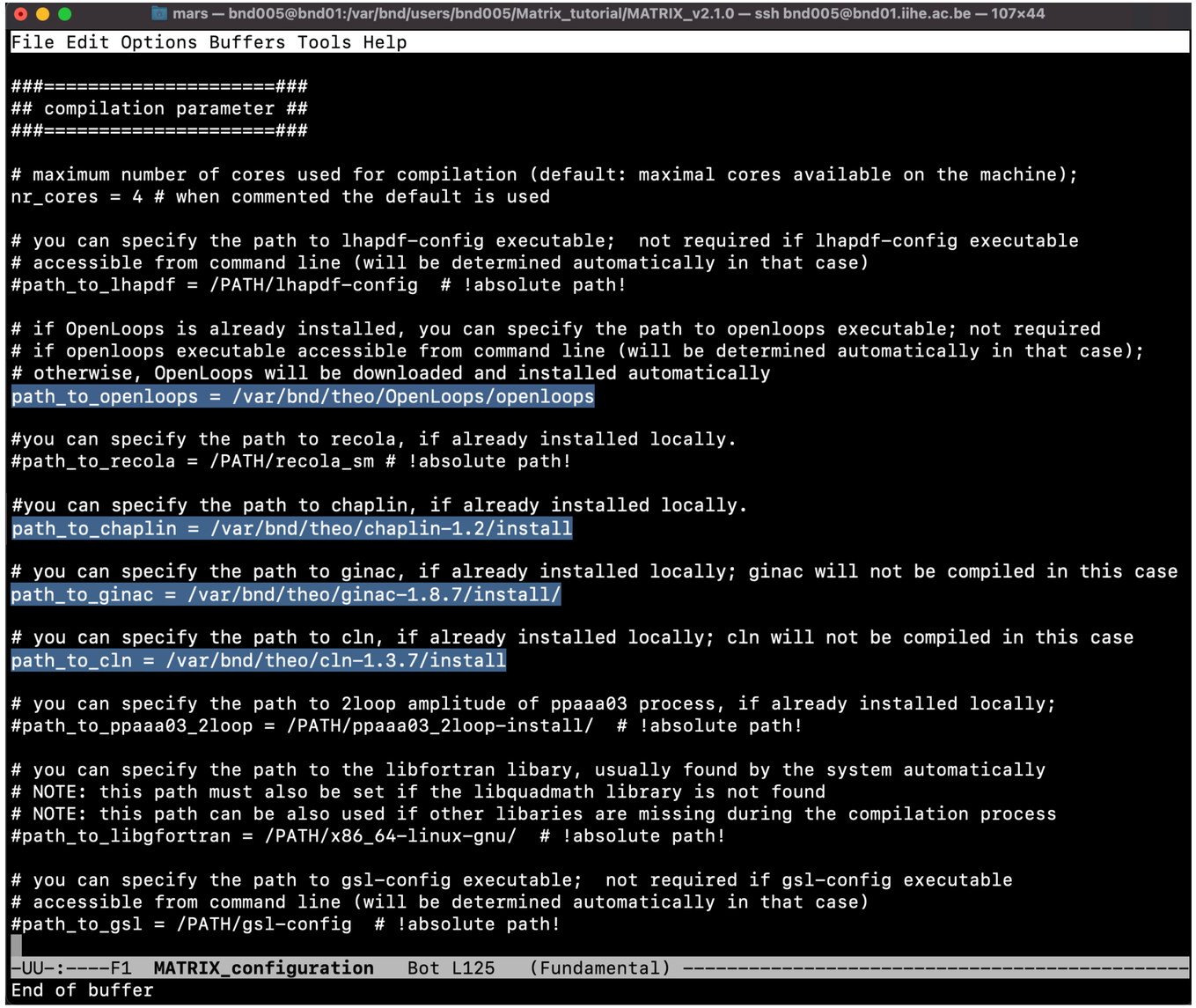
`> Ctrl-x Ctrl-s` (to save)



Hands on !

- while we are at it, also set the following other paths to speed up compilation

```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops

> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install

> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install

> path_to_cln = /var/bnd/theo/cln-1.3.7/install
```



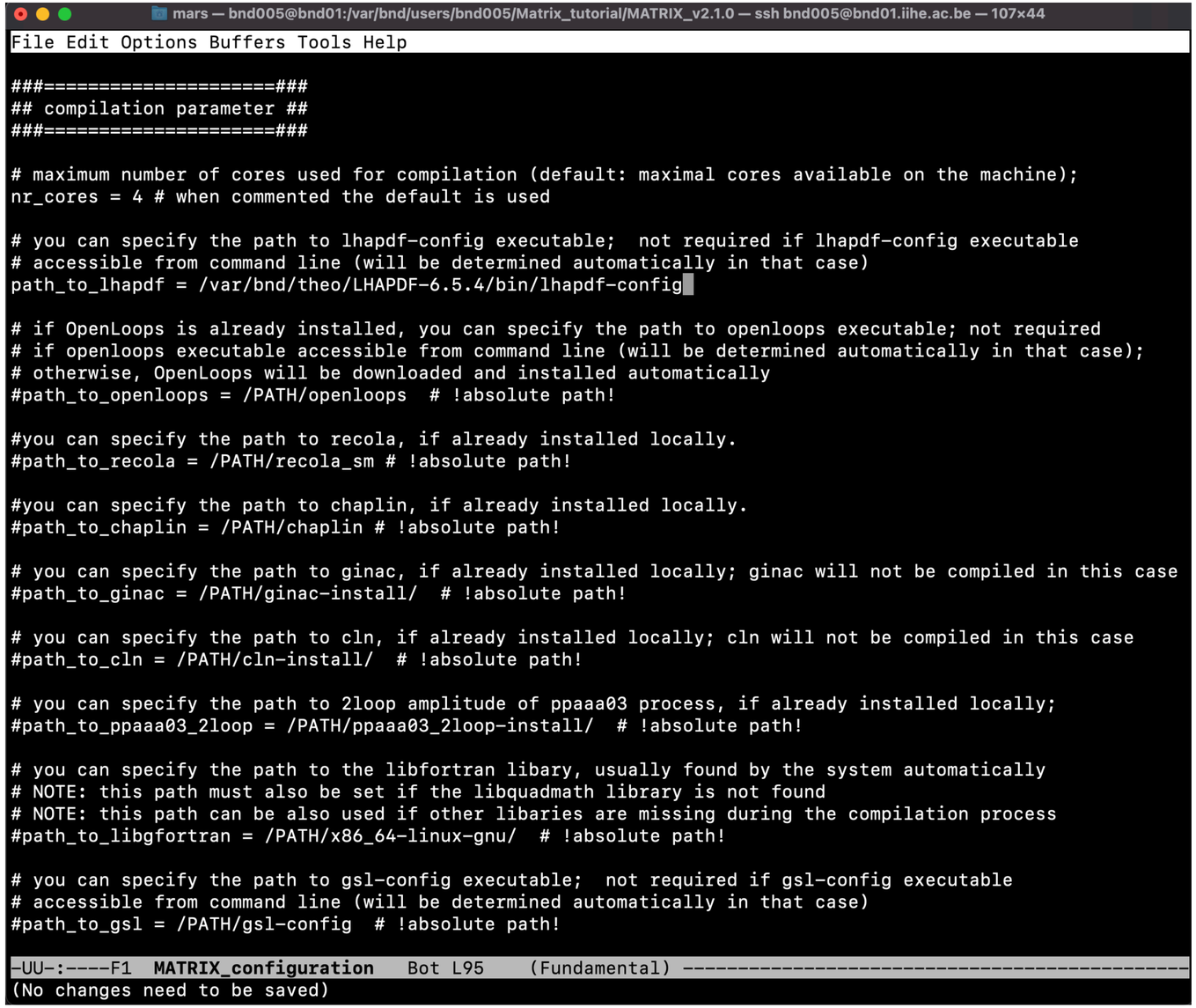
Hands on !

- while we are at it also set the following other paths to speed up compilation

```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
```

task: limit number of cores to 8 (to avoid overloading)

answer?



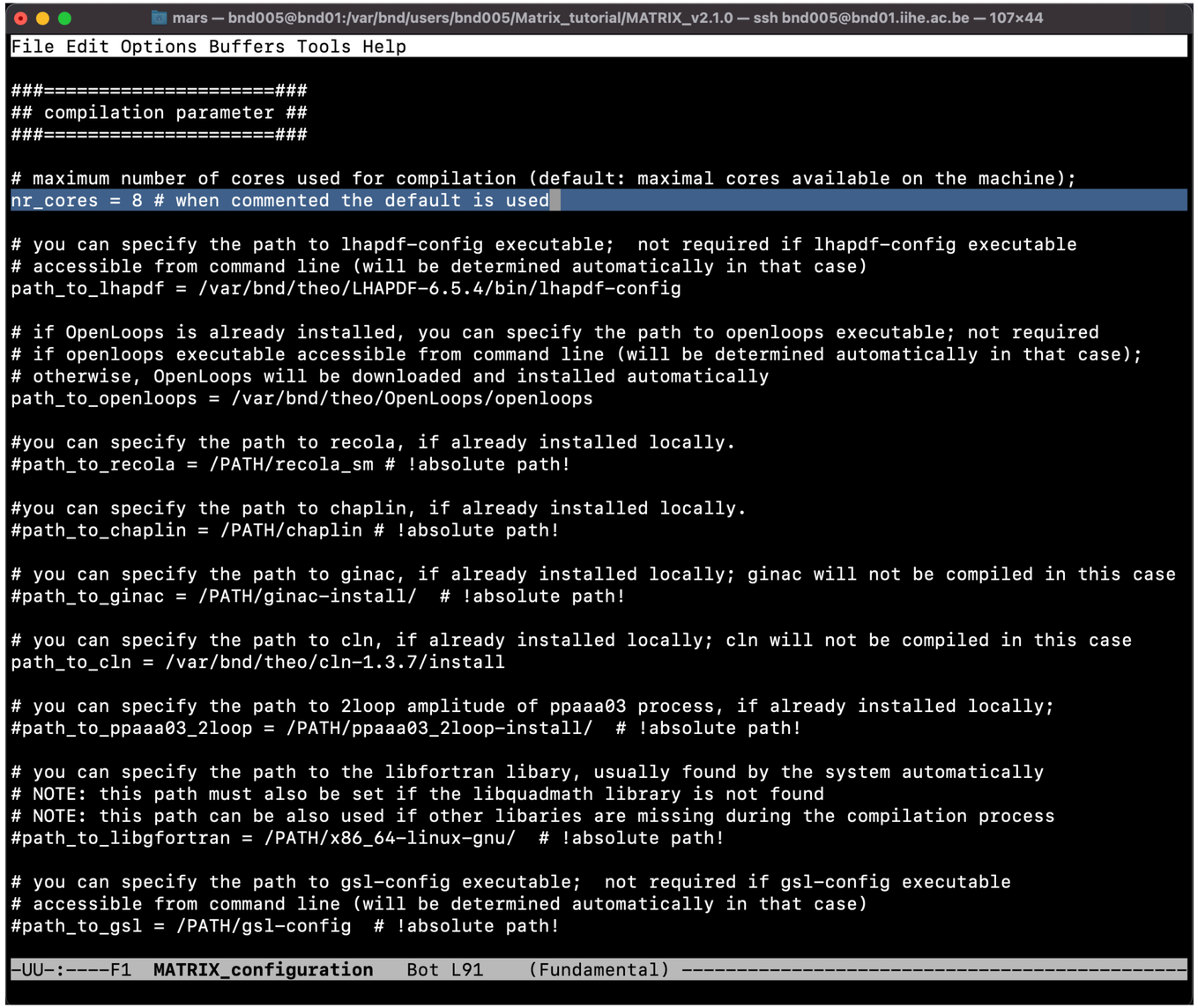
Hands on !

- while we are at it also set the following other paths to speed up compilation

```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
```

task: limit number of cores to 8 (to avoid overloading)

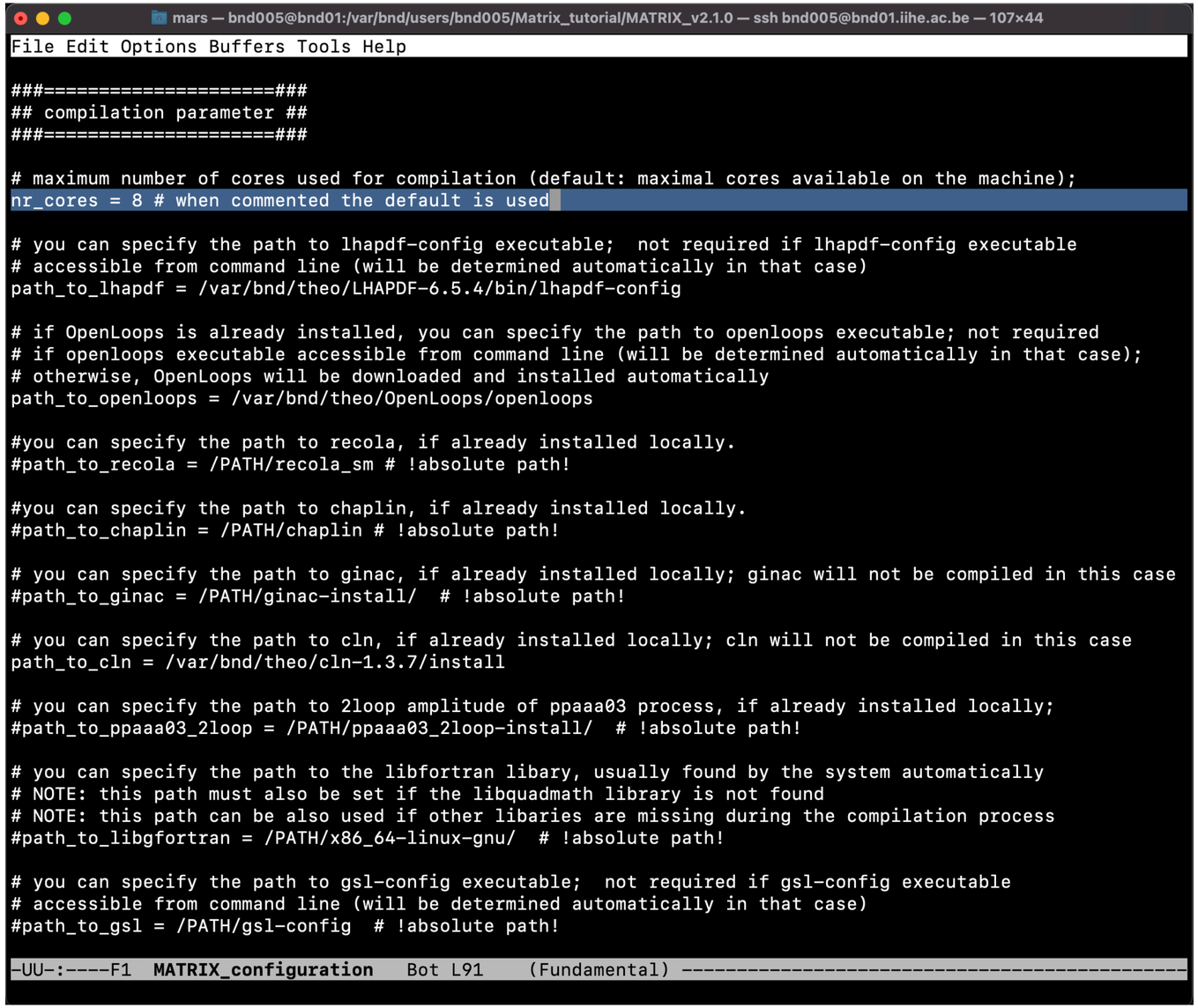
answer: set `nr_cores = 8`



Hands on !

- while we are at it also set the following other paths to speed up compilation

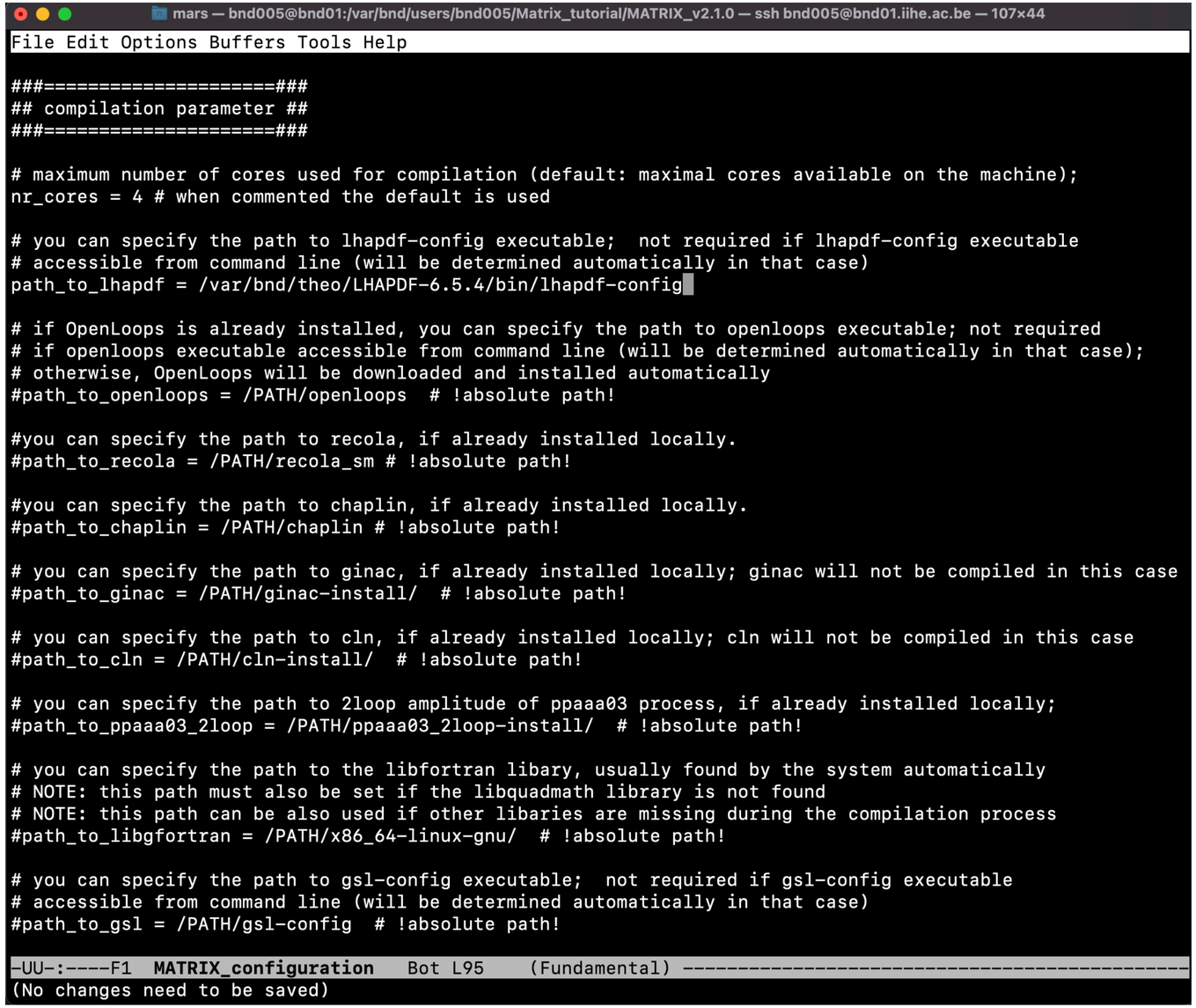
```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
> nr_cores = 8
```



Hands on !

- while we are at it also set the following other paths to speed up compilation

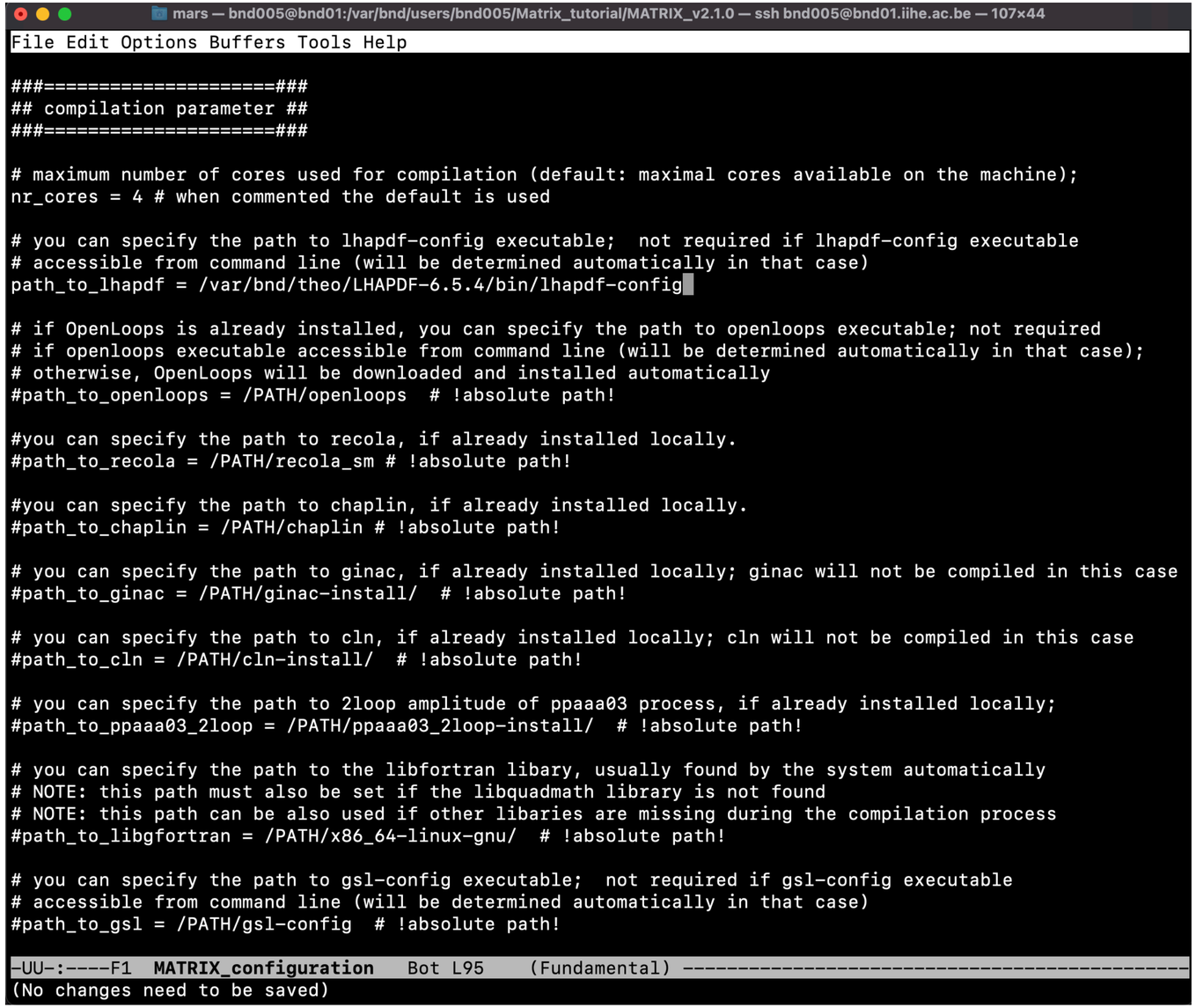
```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
> nr_cores = 8
> Ctrl-x Ctrl-s (to save)
```



Hands on !

- while we are at it also set the following other paths to speed up compilation

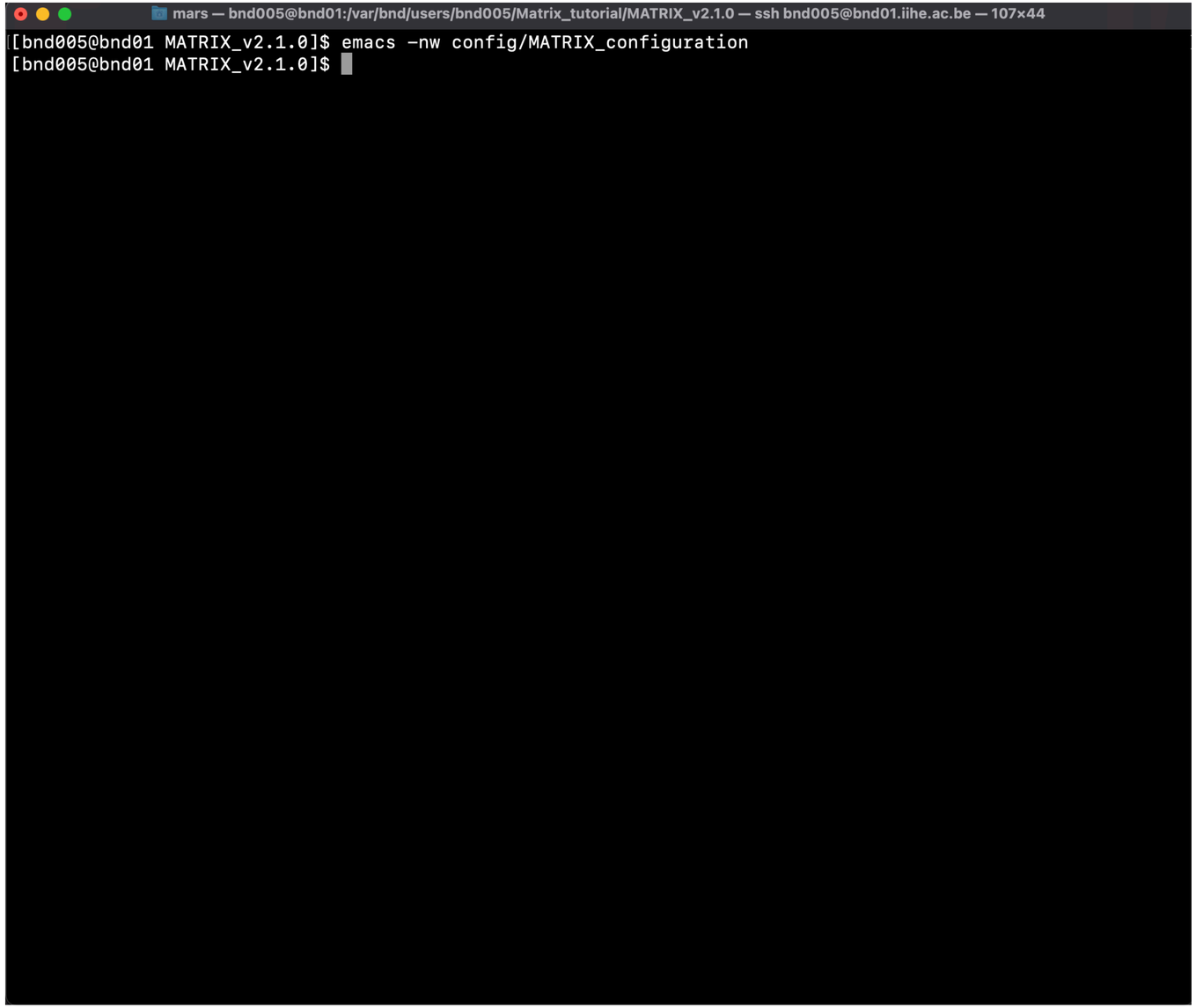
```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
> nr_cores = 8
> Ctrl-x Ctrl-s (to save)
> Ctrl-x Ctrl-c (to close the file)
```



Hands on !

- while we are at it also set the following other paths to speed up compilation

```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> path_to_ginac = /var/bnd/theo/ginac-1.8.7/install
> path_to_cln = /var/bnd/theo/cln-1.3.7/install
> nr_cores = 8
> Ctrl-x Ctrl-s (to save)
> Ctrl-x Ctrl-c (to close the file)
```



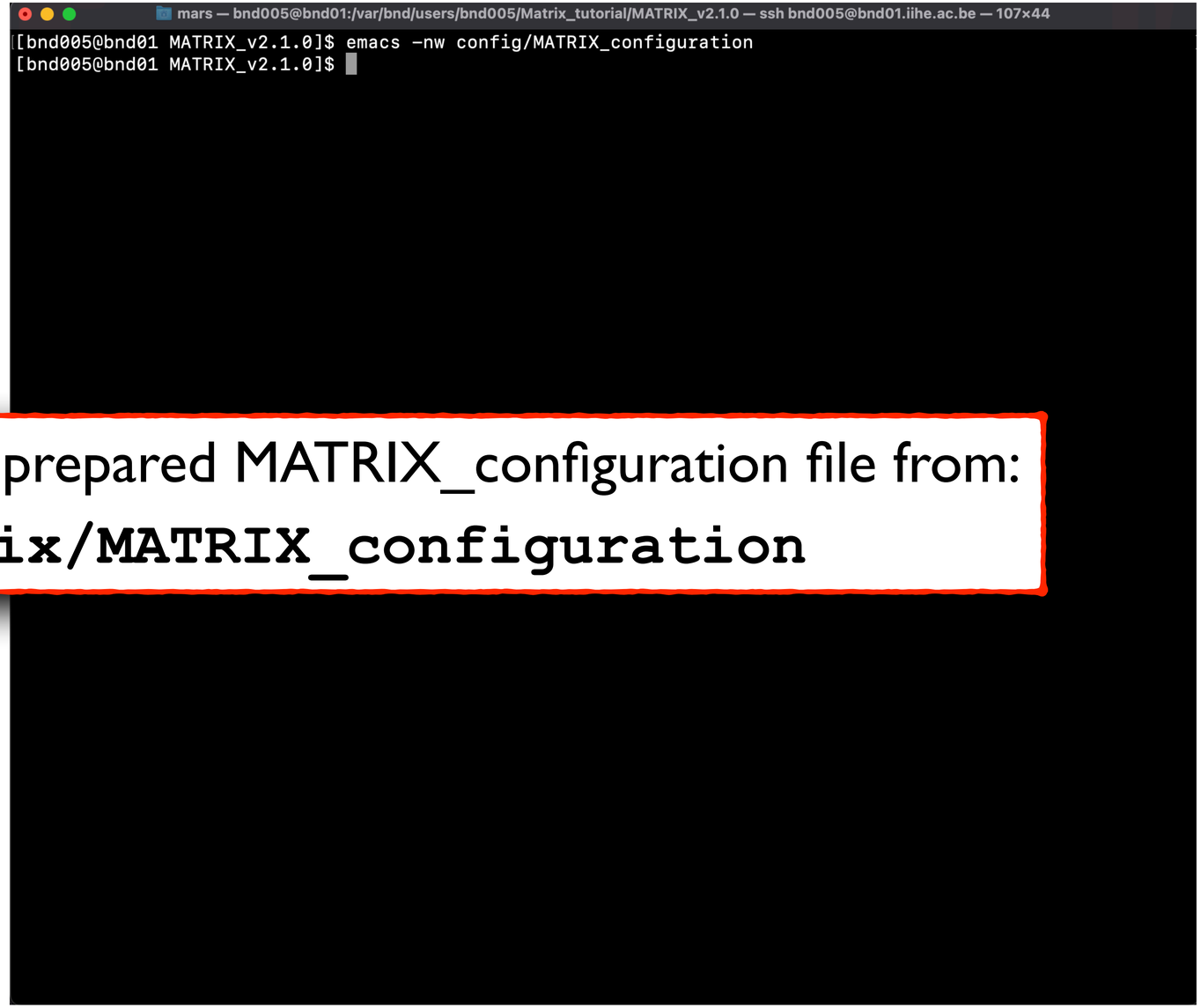
Hands on !

- while we are at it also set the following other paths to speed up compilation

```
> path_to_openloops = /var/bnd/theo/OpenLoops/openloops
> path_to_chaplin = /var/bnd/theo/chaplin-1.2/install
> th
> theo/cln-1.3.7/install
> nr_cores = 8
```

> Ctrl-x Ctrl-s (to save)

> Ctrl-x Ctrl-c (to close the file)



If you have trouble, you can copy a prepared MATRIX_configuration file from:

/var/bnd/theo/matrix/MATRIX_configuration

Hands on !

- now let's retry the compilation of the **`ppz01`** process either like before or just one line without needing to agree again to the terms

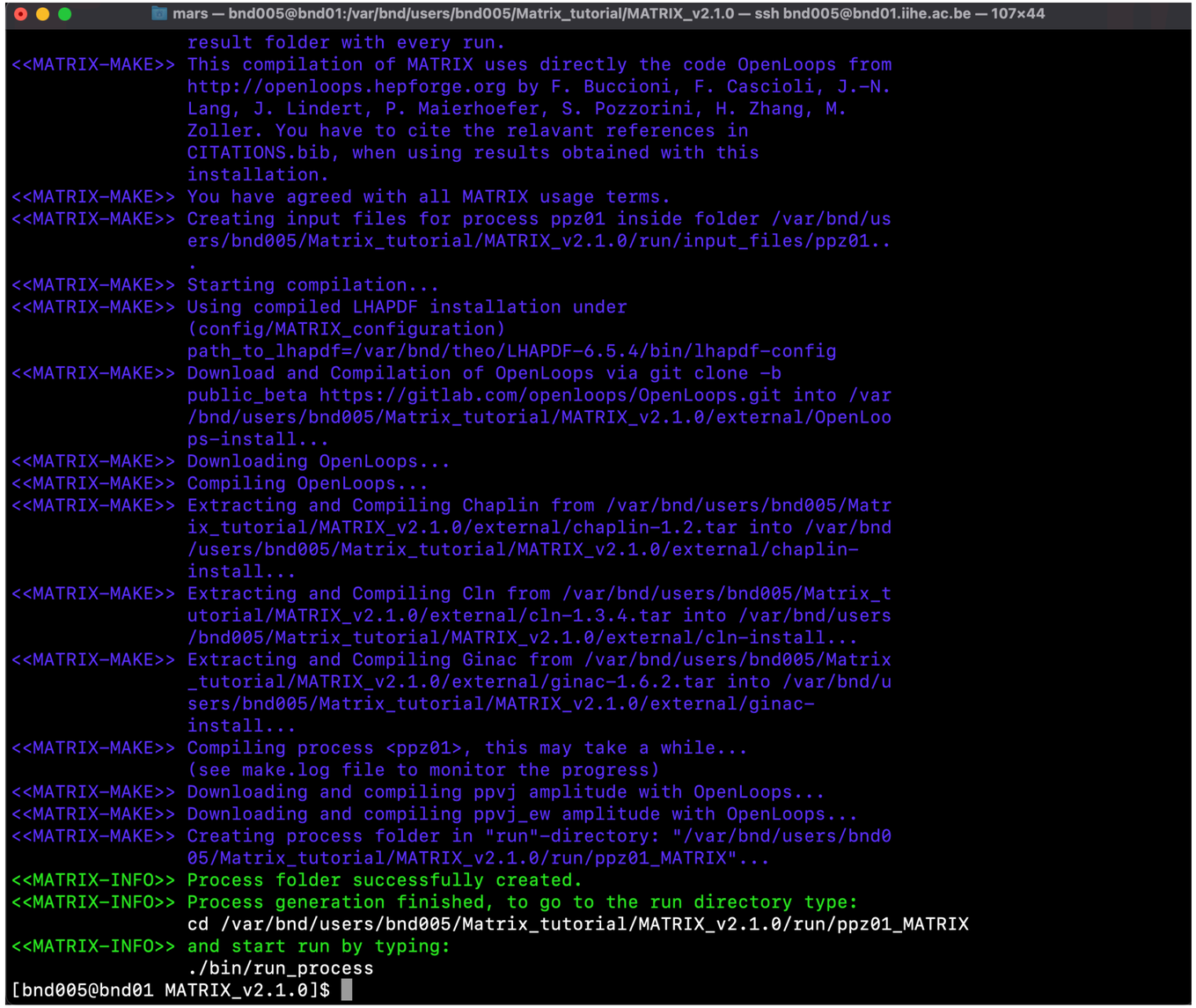
```
> ./matrix ppz01 --agree
```

Hands on !

- now let's retry the compilation of the **`ppz01`** process either like before or just one line without needing to agree again to the terms

```
> ./matrix ppz01 --agree
```

after couple of minutes → success!



Hands on !

- now let's retry the compilation of the **`ppz01`** process either like before or just one line without needing to agree again to the terms

```
> ./matrix ppz01 --agree
```

If you have trouble finishing the compilation, you can execute a bash file with the full solution that does the compilation for you from here:

`/var/bnd/theo/help/solution-1-compiliation.sh`

after couple of minutes → success!

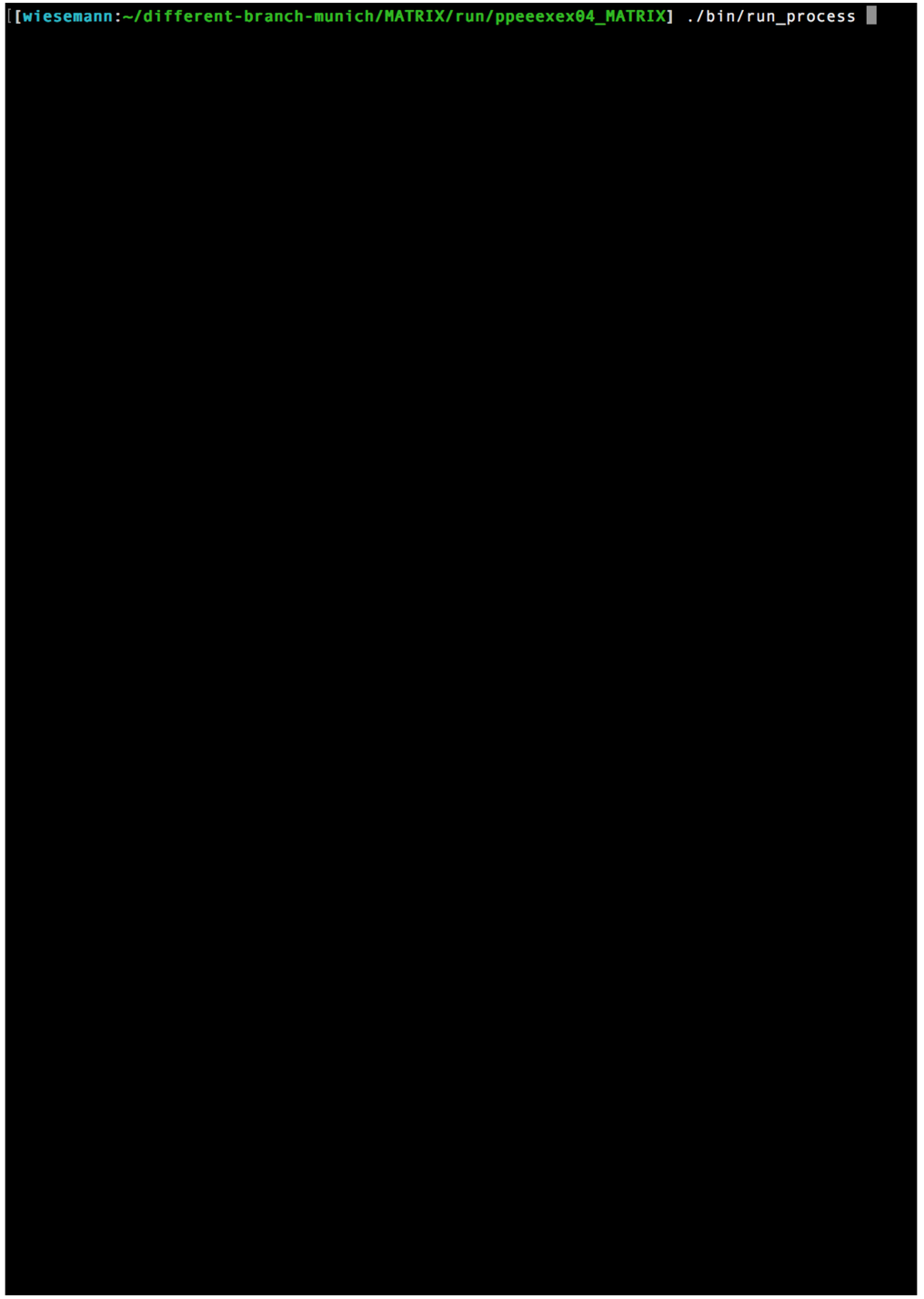
```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0 — ssh bnd005@bnd01.iihe.ac.be — 107×44
                result folder with every run.
<<MATRIX-MAKE>> This compilation of MATRIX uses directly the code OpenLoops from
                http://openloops.hepforge.org by F. Buccioni, F. Cascioli, J.-N.
                Lang, J. Lindert, P. Maierhoefer, S. Pozzorini, H. Zhang, M.
                Zoller. You have to cite the relavant references in
                CITATIONS.bib, when using results obtained with this
                installation.
<<MATRIX-MAKE>> You have agreed with all MATRIX usage terms.
<<MATRIX-MAKE>> Creating input files for process ppz01 inside folder /var/bnd/us
                ers/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/input_files/ppz01..
                .
<<MATRIX-MAKE>> Starting compilation...
<<MATRIX-MAKE>> Using compiled LHAPDF installation under
                (config/MATRIX_configuration)
                path_to_lhapdf=/var/bnd/theo/LHAPDF-6.5.4/bin/lhapdf-config
<<MATRIX-MAKE>> Download and Compilation of OpenLoops via git clone -b
                /bnd005/Matrix_tutorial/MATRIX_v2.1.0/external/cln-install...
<<MATRIX-MAKE>> Extracting and Compiling Ginac from /var/bnd/users/bnd005/Matrix
                _tutorial/MATRIX_v2.1.0/external/ginac-1.6.2.tar into /var/bnd/u
                sers/bnd005/Matrix_tutorial/MATRIX_v2.1.0/external/ginac-
                install...
<<MATRIX-MAKE>> Compiling process <ppz01>, this may take a while...
                (see make.log file to monitor the progress)
<<MATRIX-MAKE>> Downloading and compiling ppvj amplitude with OpenLoops...
<<MATRIX-MAKE>> Downloading and compiling ppvj_ew amplitude with OpenLoops...
<<MATRIX-MAKE>> Creating process folder in "run"-directory: "/var/bnd/users/bnd0
                05/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX"...
<<MATRIX-INFO>> Process folder successfully created.
<<MATRIX-INFO>> Process generation finished, to go to the run directory type:
                cd /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX
<<MATRIX-INFO>> and start run by typing:
                ./bin/run_process
[bnd005@bnd01 MATRIX_v2.1.0]$
```

How to run MATRIX

How to run

- After changing into the run directory we start the run script

```
$ ./bin/run_process
```



How to run

- After changing into the run directory we start the run script

```
$  ./bin/run_process
```

- First, choose a name for the run:

```
|===>> run_my_first_ZZ
```

How to run

- After changing into the run directory we start the run script

```
$  ./bin/run_process
```

- First, choose a name for the run:

```
|===>> run_my_first_ZZ
```

- The MATRIX run shell has many options, eg, modify input files typing:

```
|===>> parameter
|===>> model
|===>> distribution
```

```
[[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
          |                                                                   |
          |          __  __    ___    ____    ___    _   _                   |
          |         | _\/_ |   / _ \   |___|  / _ \   ||   \\   //          |
          |         || \/ ||  | |_| |    ||   ||_||   ||    \\ //           |
          |         ||    ||  | ___ |    ||   ||\\    ||    // \\           |
          |         ||    ||  ||   ||    ||   || \\   ||   //   \\          |
          |                                                                   |
          |          Version: 1.0.0.release_candidate4      Aug 2017          |
          |                                                                   |
          | Munich -- the MUlti-chaNnel Integrator at swiss (CH) precision -- |
          | Automates qT-subtraction and Resummation to Integrate X-sections  |
          |                                                                   |
          | \          \ ____      \          \ ____      \ ____      \       |
          |  \          \          |\          \          |\          |\      |
          |   )====  +   )====  +  | )====  +   )====  +  | )====  +  |-)==== |
          |  /          /          |/          /____      |/          |/      |
          | /          /           /          /           /           /       |
          |                                                                   |
          | M. Grazzini                              (grazzini@physik.uzh.ch) |
          | S. Kallweit                             (stefan.kallweit@cern.ch) |
          | M. Wiesemann                           (marius.wiesemann@cern.ch) |
          |-------------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools   |
          | from various people and groups. Please acknowledge their efforts  |
          | by citing the list of references which is created with every run. |
          \-------------------------------------------------------------------/

<<MATRIX-READ>> Type name of folder for this run (has to start with "run_").
                "ENTER" to create and use "run_01". Press TAB or type "list" to
                show existing runs. Type "exit" or "quit" to stop. Any other
                folder will be created.
[|============>> run_my_first_ZZ
<<MATRIX-READ>> Type one of the following commands: ("TAB" for auto-completion)
-------------------------------------------------------------------------------
General commands    ||   description
-------------------------------------------------------------------------------
help                >>   Show help menu.
help <command>      >>   Show help message for specific <command>.
list                >>   List available commands again.
exit                >>   Stop the code.
quit                >>   Stop the code.
-------------------------------------------------------------------------------
Input to modify     ||   description
-------------------------------------------------------------------------------
parameter           >>   Modify "parameter.dat" input file in editor.
model               >>   Modify "model.dat" input file in editor.
distribution        >>   Modify "distribution.dat" input file in editor.
-------------------------------------------------------------------------------
Run-mode to start   ||   description
-------------------------------------------------------------------------------
run                 >>   Start cross section computation in standard mode.
run_grid            >>   Start only grid setup phase.
run_pre             >>   Start only extrapolation (grid must be already done).
run_pre_and_main    >>   Start after grid setup (grid must be already done).
run_main            >>   Start only main run (other runs must be already done).
run_results         >>   Start only result combination.
run_gnuplot         >>   Start only gnuplotting the results.
setup_run           >>   Setup the run folder, but not start running.
delete_run          >>   Remove run folder (including input/log/result).
tar_run             >>   Create <run_folder>.tar (including input/log/result).
[|============>> parameter
[|============>> model
[|============>> distribution
```

How to run

- After changing into the r
  we start the run script

```
$ ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
```

```
[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
#########################
# MATRIX input parameter #
#########################

#---------------------\
# general run settings |
#---------------------/
process_class   =  pp-ememepep+X  #  process id
E               =  6500.          #  energy per beam
coll_choice     =  1              #  (1) PP collider; (2) PPbar collider
switch_off_shell = 0              #  switch for effective integration for off-shell Z bosons (eg, Higgs analysis)


#---------------\
# scale settings |
#---------------/
scale_ren       =  91.1876        #  renormalization (muR) scale
scale_fact      =  91.1876        #  factorization (muF) scale
dynamic_scale   =  0              #  dynamic ren./fac. scale
                                  #  0: fixed scale above
                                  #  1: invariant mass (Q) of system (of the colourless final states)
                                  #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final states)
factor_central_scale = 1          #  relative factor for central scale (important for dynamic scales)
scale_variation  = 1              #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-point va
variation_factor = 2              #  symmetric variation factor; usually a factor of 2 up and down (default)


#----------------------------\
# order-dependent run settings |
#----------------------------/
# LO
run_LO          =  1              #  switch for LO cross section (1) on; (0) off
LHAPDF_LO       =  NNPDF30_lo_as_0118 #  LO LHAPDF set
PDFsubset_LO    =  0              #  member of LO PDF set
precision_LO    =  1.e-2          #  precision of LO cross section

# NLO
run_NLO         =  0              #  switch for NLO cross section (1) on; (0) off
LHAPDF_NLO      =  NNPDF30_nlo_as_0118 #  NLO LHAPDF set
PDFsubset_NLO   =  0              #  member of NLO PDF set
precision_NLO   =  1.e-2          #  precision of NLO cross section
NLO_subtraction_method = 1        #  switch to use (2) qT subtraction (1) Catani-Seymour at NLO

# NNLO
run_NNLO        =  0              #  switch for NNLO cross section (1) on; (0) off
LHAPDF_NNLO     =  NNPDF30_nnlo_as_0118 #  NNLO LHAPDF set
PDFsubset_NNLO  =  0              #  member of NNLO PDF set
precision_NNLO  =  1.e-2          #  precision of NNLO cross section
loop_induced    =  1              #  switch to turn on (1) and off (0) loop-induced gg channel


#---------------------------\
# settings for fiducial cuts |
#---------------------------/
# Jet algorithm
jet_algorithm = 3                 #  (1) Cambridge-Aachen (2) kT (3) anti-kT
jet_R_definition = 0              #  (0) pseudo-rapidity (1) rapidity
jet_R = 0.4                       #  DeltaR

# Jet cuts
define_pT jet = 25.               #  requirement on jet transverse momentum (lower cut)
define_eta jet = 4.5              #  requirement on jet pseudo-rapidity (upper cut)
define_y jet = 1.e99              #  requirement on jet rapidity (upper cut)
n_observed_min jet = 0            #  minimal number of observed jets (with cuts above)
n_observed_max jet = 99           #  maximal number of observed jets (with cuts above)
```

```
-UU-:----F1  parameter.dat    Top (1,0)     Git-release_candidate  (Fundamental Fld) 8:56AM 4.63 ----------------
Folding buffer... done
```

How to run

- After changing into the r
  we start the run script

```
$ ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
```

  - adjust scales

```
scale_fact = 91.1876
scale_ren  = 91.1876
```

```
[wiesemann:~/munich-http/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
#########################
# MATRIX input parameter #
#########################

#---------------------\
# general run settings |
#---------------------/
process_class   =  pp-ememepep+X  #  process id
E               =  6500.          #  energy per beam
coll_choice     =  1              #  (1) PP collider; (2) PPbar collider
switch_off_shell = 0              #  switch for effective integration for off-shell Z bosons (eg, Higgs analysis)


#---------------\
# scale settings |
#---------------/
scale_ren       =  91.1876        #  renormalization (muR) scale
scale_fact      =  91.1876        #  factorization (muF) scale
dynamic_scale   =  0              #  dynamic ren./fac. scale
                                  #  0: fixed scale above
                                  #  1: invariant mass (Q) of system (of the colourless final states)
                                  #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final states)
factor_central_scale = 1          #  relative factor for central scale (important for dynamic scales)
scale_variation  = 1              #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-point v
variation_factor = 2              #  symmetric variation factor; usually a factor of 2 up and down (default)


#----------------------------\
# order-dependent run settings |
#----------------------------/
# LO
run_LO          =  1              #  switch for LO cross section (1) on; (0) off
LHAPDF_LO       =  NNPDF30_lo_as_0118 #  LO LHAPDF set
PDFsubset_LO    =  0              #  member of LO PDF set
precision_LO    =  1.e-2          #  precision of LO cross section

# NLO
run_NLO         =  0              #  switch for NLO cross section (1) on; (0) off
LHAPDF_NLO      =  NNPDF30_nlo_as_0118 #  NLO LHAPDF set
PDFsubset_NLO   =  0              #  member of NLO PDF set
precision_NLO   =  1.e-2          #  precision of NLO cross section
NLO_subtraction_method = 1        #  switch to use (2) qT subtraction (1) Catani-Seymour at NLO

# NNLO
run_NNLO        =  0              #  switch for NNLO cross section (1) on; (0) off
LHAPDF_NNLO     =  NNPDF30_nnlo_as_0118 #  NNLO LHAPDF set
PDFsubset_NNLO  =  0              #  member of NNLO PDF set
precision_NNLO  =  1.e-2          #  precision of NNLO cross section
loop_induced    =  1              #  switch to turn on (1) and off (0) loop-induced gg channel


#---------------------------\
# settings for fiducial cuts |
#---------------------------/
# Jet algorithm
jet_algorithm = 3                 #  (1) Cambridge-Aachen (2) kT (3) anti-kT
jet_R_definition = 0              #  (0) pseudo-rapidity (1) rapidity
jet_R = 0.4                       #  DeltaR

# Jet cuts
define_pT jet = 25.               #  requirement on jet transverse momentum (lower cut)
define_eta jet = 4.5              #  requirement on jet pseudo-rapidity (upper cut)
define_y jet = 1.e99              #  requirement on jet rapidity (upper cut)
n_observed_min jet = 0            #  minimal number of observed jets (with cuts above)
n_observed_max jet = 99           #  maximal number of observed jets (with cuts above)
```

```
-UU-:----F1  parameter.dat    Top (1,0)     Git-release_candidate  (Fundamental Fld) 8:58AM 4.23 ----------
Folding buffer... done
```

How to run

- After changing into the r
  we start the run script

```
$ ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
```

- adjust scales

```
scale_fact = 91.1876
scale_ren  = 91.1876
```

- adjust precision at LO

```
precision_LO = 1.e-3
```

```
[wiesemann:~/munich-http/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
##########################
# MATRIX input parameter #
##########################

#---------------------\
# general run settings |
#---------------------/
process_class   =  pp-ememepep+X  #  process id
E               =  6500.          #  energy per beam
coll_choice     =  1              #  (1) PP collider; (2) PPbar collider
switch_off_shell = 0              #  switch for effective integration for off-shell Z bosons (eg, Higgs analysis)


#---------------\
# scale settings |
#---------------/
scale_ren       =  91.1876        #  renormalization (muR) scale
scale_fact      =  91.1876        #  factorization (muF) scale
dynamic_scale   =  0              #  dynamic ren./fac. scale
                                  #  0: fixed scale above
                                  #  1: invariant mass (Q) of system (of the colourless final states)
                                  #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final states)
factor_central_scale = 1          #  relative factor for central scale (important for dynamic scales)
scale_variation  = 1              #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-point v
variation_factor = 2              #  symmetric variation factor; usually a factor of 2 up and down (default)


#-----------------------------\
# order-dependent run settings |
#-----------------------------/
# LO
run_LO          =  1              #  switch for LO cross section (1) on; (0) off
LHAPDF_LO       =  NNPDF30_lo_as_0118 #  LO LHAPDF set
PDFsubset_LO    =  0              #  member of LO PDF set
precision_LO    =  1.e-2          #  precision of LO cross section

# NLO
run_NLO         =  0              #  switch for NLO cross section (1) on; (0) off
LHAPDF_NLO      =  NNPDF30_nlo_as_0118 #  NLO LHAPDF set
PDFsubset_NLO   =  0              #  member of NLO PDF set
precision_NLO   =  1.e-2          #  precision of NLO cross section
NLO_subtraction_method = 1        #  switch to use (2) qT subtraction (1) Catani-Seymour at NLO

# NNLO
run_NNLO        =  0              #  switch for NNLO cross section (1) on; (0) off
LHAPDF_NNLO     =  NNPDF30_nnlo_as_0118 #  NNLO LHAPDF set
PDFsubset_NNLO  =  0              #  member of NNLO PDF set
precision_NNLO  =  1.e-2          #  precision of NNLO cross section
loop_induced    =  1              #  switch to turn on (1) and off (0) loop-induced gg channel


#---------------------------\
# settings for fiducial cuts |
#---------------------------/
# Jet algorithm
jet_algorithm = 3                 #  (1) Cambridge-Aachen (2) kT (3) anti-kT
jet_R_definition = 0              #  (0) pseudo-rapidity (1) rapidity
jet_R = 0.4                       #  DeltaR

# Jet cuts
define_pT jet = 25.               #  requirement on jet transverse momentum (lower cut)
define_eta jet = 4.5              #  requirement on jet pseudo-rapidity (upper cut)
define_y jet = 1.e99              #  requirement on jet rapidity (upper cut)
n_observed_min jet = 0            #  minimal number of observed jets (with cuts above)
n_observed_max jet = 99           #  maximal number of observed jets (with cuts above)
```

```
-UU-:----F1  parameter.dat    Top (1,0)     Git-release_candidate  (Fundamental Fld) 8:58AM 4.23 ----------
Folding buffer... done
```

How to run

- After changing into the r
  we start the run script

```
$ ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
```

- adjust scales

```
scale_fact = 91.1876
scale_ren  = 91.1876
```

- adjust precision at LO

```
precision_LO = 1.e-3
```

- turn on NLO/NNLO

```
run_(N)NLO = 1
```

```
[wiesemann:~/munich-http/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
#########################
# MATRIX input parameter #
#########################

#---------------------\
# general run settings |
#---------------------/
process_class   =  pp-ememepep+X  #  process id
E               =  6500.          #  energy per beam
coll_choice     =  1              #  (1) PP collider; (2) PPbar collider
switch_off_shell = 0              #  switch for effective integration for off-shell Z bosons (eg, Higgs analysis)


#---------------\
# scale settings |
#---------------/
scale_ren       =  91.1876        #  renormalization (muR) scale
scale_fact      =  91.1876        #  factorization (muF) scale
dynamic_scale   =  0              #  dynamic ren./fac. scale
                                  #  0: fixed scale above
                                  #  1: invariant mass (Q) of system (of the colourless final states)
                                  #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final states)
factor_central_scale = 1          #  relative factor for central scale (important for dynamic scales)
scale_variation  = 1              #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-point va
variation_factor = 2              #  symmetric variation factor; usually a factor of 2 up and down (default)


#-----------------------------\
# order-dependent run settings |
#-----------------------------/
# LO
run_LO          =  1              #  switch for LO cross section (1) on; (0) off
LHAPDF_LO       =  NNPDF30_lo_as_0118 #  LO LHAPDF set
PDFsubset_LO    =  0              #  member of LO PDF set
precision_LO    =  1.e-2          #  precision of LO cross section

# NLO
run_NLO         =  0              #  switch for NLO cross section (1) on; (0) off
LHAPDF_NLO      =  NNPDF30_nlo_as_0118 #  NLO LHAPDF set
PDFsubset_NLO   =  0              #  member of NLO PDF set
precision_NLO   =  1.e-2          #  precision of NLO cross section
NLO_subtraction_method = 1        #  switch to use (2) qT subtraction (1) Catani-Seymour at NLO

# NNLO
run_NNLO        =  0              #  switch for NNLO cross section (1) on; (0) off
LHAPDF_NNLO     =  NNPDF30_nnlo_as_0118 #  NNLO LHAPDF set
PDFsubset_NNLO  =  0              #  member of NNLO PDF set
precision_NNLO  =  1.e-2          #  precision of NNLO cross section
loop_induced    =  1              #  switch to turn on (1) and off (0) loop-induced gg channel


#---------------------------\
# settings for fiducial cuts |
#---------------------------/
# Jet algorithm
jet_algorithm = 3                 #  (1) Cambridge-Aachen (2) kT (3) anti-kT
jet_R_definition = 0              #  (0) pseudo-rapidity (1) rapidity
jet_R = 0.4                       #  DeltaR

# Jet cuts
define_pT jet = 25.               #  requirement on jet transverse momentum (lower cut)
define_eta jet = 4.5              #  requirement on jet pseudo-rapidity (upper cut)
define_y jet = 1.e99              #  requirement on jet rapidity (upper cut)
n_observed_min jet = 0            #  minimal number of observed jets (with cuts above)
n_observed_max jet = 99           #  maximal number of observed jets (with cuts above)
```

```
-UU-:----F1  parameter.dat    Top (1,0)     Git-release_candidate  (Fundamental Fld) 9:55AM 4.13 ----------
Folding buffer... done
```

How to run

- After changing into the r
  we start the run script

```
$  ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell
  options, eg, modify input

```
|===>> parameter
```

- adjust scales

```
scale_fact = 91.1876
scale_ren  = 91.1876
```

- adjust precision at LO

```
precision_LO = 1.e-3
```

- turn on NLO/NNLO

```
run_(N)NLO = 1
```

- set rough run-time estimate

```
max_time_per_job
```

```
[wiesemann:~/munich-http/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
# Negatively-charged lepton cuts
define_pT nclep = 7.           #  requirement on negatively-charged lepton transverse momentum (lower cut)
define_eta nclep = 2.7         #  requirement on negatively-charged lepton pseudo-rapidity (upper cut)
define_y nclep = 1.e99         #  requirement on negatively-charged lepton rapidity (upper cut)
n_observed_min nclep = 0       #  minimal number of observed negatively-charged leptons (with cuts above)
n_observed_max nclep = 99      #  maximal number of observed negatively-charged leptons (with cuts above)

# Positively-charged lepton cuts
define_pT pclep = 7.           #  requirement on positively-charged lepton transverse momentum (lower cut)
define_eta pclep = 2.7         #  requirement on positively-charged lepton pseudo-rapidity (upper cut)
define_y pclep = 1.e99         #  requirement on positively-charged lepton rapidity (upper cut)
n_observed_min pclep = 0       #  minimal number of observed positively-charged leptons (with cuts above)
n_observed_max pclep = 99      #  maximal number of observed positively-charged leptons (with cuts above)



# Blocks with user-defined cuts (only used if defined in 'MATRIX/prc/$process/user/specify.cuts.cxx')
# Mandatory cuts for this process (ensure IR safety):
# -- (user_switch M_leplep_OSSF AND user_cut min_M_leplep_OSSF) OR (user_switch R_leplep AND user_cut min_R_leple
# Z-boson reconstruction:
user_switch lepton_identification = 1 #  switch to identify leptons from Z-bosons; (0) off (1) ATLAS (2) CMS

user_switch M_Zrec = 1         #  switch for invariant mass cut on reconstructed Z-bosons; requires: lepton_ident
user_cut min_M_Zrec = 66.      #  requirement on reconstructed Z-boson invariant mass (lower cut)
user_cut max_M_Zrec = 116.     #  requirement on reconstructed Z-boson invariant mass (upper cut)

user_switch M_leplep_OSSF = 0  #  switch to turn on (1) and off (0) cuts on OSSF lepton-lepton invariant mass
user_cut min_M_leplep_OSSF = 0 #  requirement on OSSF lepton-lepton invariant mass (lower cut) to ensure IR safet

user_switch R_leplep = 1       #  switch to turn on (1) and off (0) cuts on lepton-lepton separation
user_cut min_R_leplep = 0.2    #  requirement on lepton-lepton separation in y-phi-plane (lower cut)

user_switch pT_lep_1st = 0     #  switch to turn on (1) and off (0) cuts on pT of hardest lepton
user_cut min_pT_lep_1st = 0    #  requirement on pT of hardest lepton (lower cut)

user_switch pT_lep_2nd = 0     #  switch to turn on (1) and off (0) cuts on pT of second-hardest lepton
user_cut min_pT_lep_2nd = 0    #  requirement on pT of second-hardest lepton (lower cut)

user_switch M_4lep = 0         #  switch to turn on (1) and off (0) cuts on invariant of 4-lepton system
user_cut min_M_4lep = 120      #  requirement on invariant mass of 4-lepton system (lower cut)
user_cut max_M_4lep = 130      #  requirement on invariant mass of 4-lepton system (upper cut)
user_cut min_delta_M_4lep = 1.e99 #  minimal difference of 4-lepton invariant mass to PDG Z mass
user_cut max_delta_M_4lep = 0     #  maximal difference of 4-lepton invariant mass to PDG Z mass

user_switch lep_iso = 0        #  switch to turn on (1) and off (0) isolation between leptons
user_cut lep_iso_delta_0 = 0.4 #  lepton isolation cone size
user_cut lep_iso_epsilon = 0.4 #  lepton isolation threshold ratio


#-----------------\
# MATRIX behavior |
#-----------------/
max_time_per_job = 12          #  very rough time(hours) one main run job shall take (default: 24h)
                               #  unreliable when < 1h, use as tuning parameter for degree of parallelization
                               #  note: becomes ineffective when job number > max_nr_parallel_jobs
                               #        which is set in MATRIX_configuration file
switch_distribution = 1        #  switch to turn on (1) and off (0) distributions
save_previous_result = 1       #  switch to save previous result of this run (in result/"run"/saved_result_$i)
save_previous_log = 0          #  switch to save previous log of this run (in log/"run"/saved_result_$i)
#include_pre_in_results = 0     #  switch to (0) only include main run in results; (1) also all extrapolation (pr
                               #  crucial to set to 0 if re-running main with different inputs (apart from precis
                               #  note: if missing (default) pre runs used if important for precision
                               #        (separately for each contribution);
reduce_workload = 0            #  switch to keep full job output (0), reduce (1) or minimize (2) workload on slow
random_seed = 0                #  specify integer value (grid-/pre-run reproducible)
```

```
-UU-:**--F1  parameter.dat    Bot (108,0)    Git-release_candidate  (Fundamental Fld) 9:56AM 4.63 ----------------
```

How to run

- After changing into the run directory we start the run script

```
$  ./bin/run_process
```

- First, choose a name for the run:

```
|===>> run_my_first_ZZ
```

- The MATRIX run shell has many options, eg, modify input files typing:

```
|===>> parameter
```

```
|===>> model
```

```
[[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library         |
          |                                                                  |
          |          __  __    ___     ____    ___    _                     |
          |         | _\/_ |   / _ \   |____|  / _ \   ||   \\   //         |
          |         || \/ ||  | |_| |    ||    ||_||   ||    \\ //          |
          |         ||    ||  | ___ |    ||    ||\\    ||    // \\          |
          |         ||    ||  ||   ||    ||    || \\   ||   //   \\         |
          |                                                                  |
          |          Version: 1.0.0.release_candidate4      Aug 2017         |
          |                                                                  |
          | Munich -- the MUlti-chaNnel Integrator at swiss (CH) precision -- |
          | Automates qT-subtraction and Resummation to Integrate X-sections |
          |                                                                  |
          | \          \ ____      \          \ ____      \ ____      \      |
          |  \          \          |\          \          |\          |\     |
          |   )====  +   )====  +  | )====  +   )====  +  | )====  +  |-)==== |
          |  /          /          |/          /____      |/          |/     |
          | /          /           /          /          /           /      |
          |                                                                  |
          | M. Grazzini                              (grazzini@physik.uzh.ch) |
          | S. Kallweit                             (stefan.kallweit@cern.ch) |
          | M. Wiesemann                           (marius.wiesemann@cern.ch) |
          |------------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools  |
          | from various people and groups. Please acknowledge their efforts |
          | by citing the list of references which is created with every run. |
          \------------------------------------------------------------------/

<<MATRIX-READ>> Type name of folder for this run (has to start with "run_").
                "ENTER" to create and use "run_01". Press TAB or type "list" to
                show existing runs. Type "exit" or "quit" to stop. Any other
                folder will be created.
[|============>> run_my_first_ZZ
<<MATRIX-READ>> Type one of the following commands: ("TAB" for auto-completion)
--------------------------------------------------------------------------------
General commands    ||   description
--------------------------------------------------------------------------------
help                >>   Show help menu.
help <command>      >>   Show help message for specific <command>.
list                >>   List available commands again.
exit                >>   Stop the code.
quit                >>   Stop the code.
--------------------------------------------------------------------------------
Input to modify     ||   description
--------------------------------------------------------------------------------
parameter           >>   Modify "parameter.dat" input file in editor.
model               >>   Modify "model.dat" input file in editor.
distribution        >>   Modify "distribution.dat" input file in editor.
--------------------------------------------------------------------------------
Run-mode to start   ||   description
--------------------------------------------------------------------------------
run                 >>   Start cross section computation in standard mode.
run_grid            >>   Start only grid setup phase.
run_pre             >>   Start only extrapolation (grid must be already done).
run_pre_and_main    >>   Start after grid setup (grid must be already done).
run_main            >>   Start only main run (other runs must be already done).
run_results         >>   Start only result combination.
run_gnuplot         >>   Start only gnuplotting the results.
setup_run           >>   Setup the run folder, but not start running.
delete_run          >>   Remove run folder (including input/log/result).
tar_run             >>   Create <run_folder>.tar (including input/log/result).
[|============>> parameter
|============>> model
```

How to run

- After changing into the r
  we start the run script

```
$  ./bin/run_proces
```

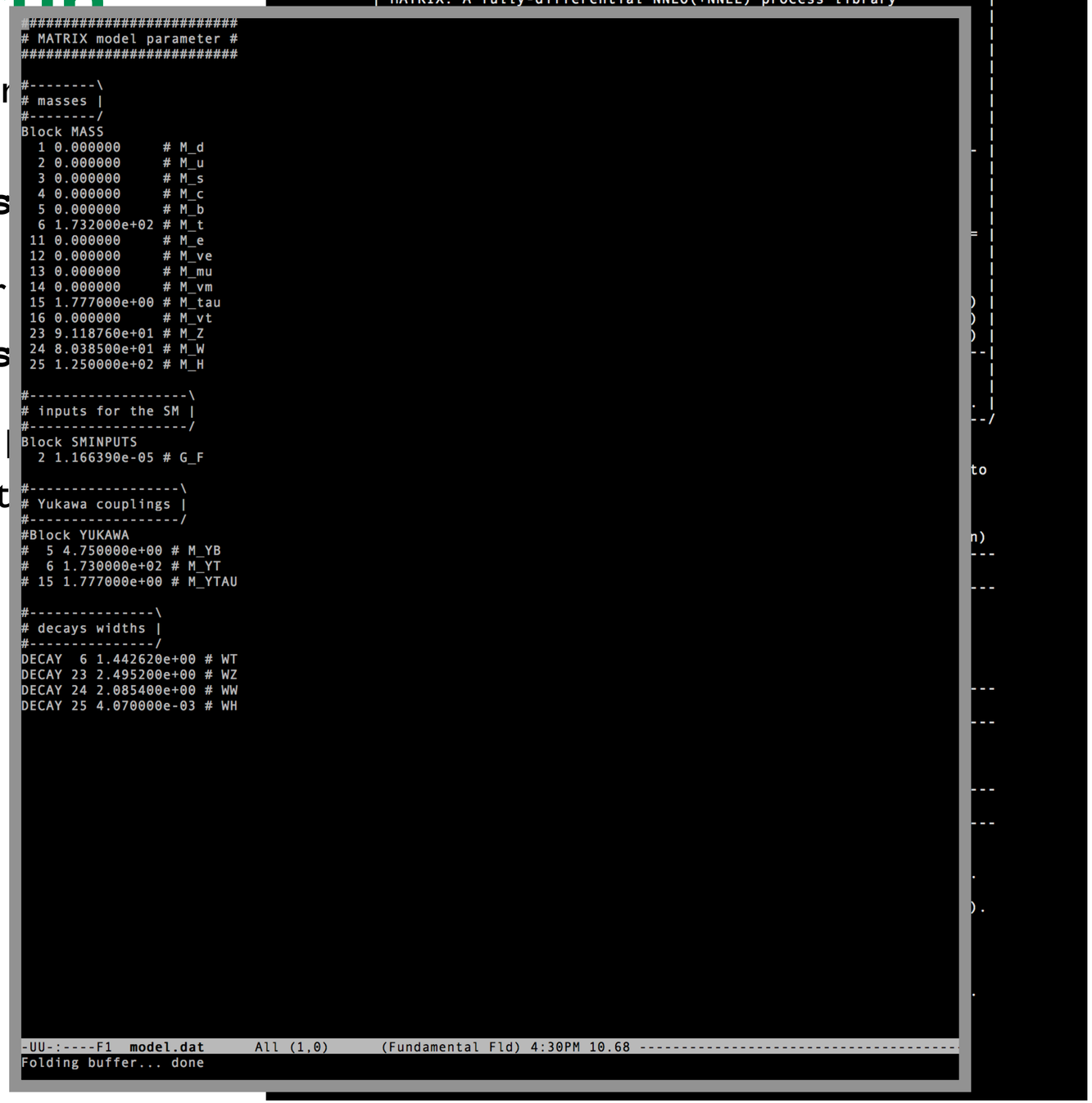
- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
```

```
|===>> model
```



How to run

- After changing into the r
  we start the run script

```
$  ./bin/run_proces
```

- First, choose a name for

```
|===>> run_my_firs
```

- The MATRIX run shell l
  options, eg, modify input

```
|===>> parameter
|===>> model
|===>> distributio
```

```
[[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
```

```
##################################
# MATRIX distribution definition #
##################################
#
# In this file you can customize the distributions created during the run (examples below)
# please read the INSTRUCTIONS at the END OF THIS FILE...
#
#------\
# Info |
#------/
# Total rates and jet multiplicities (possibly within cuts) will automatically be included
# Add/remove arbitrary distribution-blocks, but always add/remove a full block.
#
#---------------------\
# define distributions |
#---------------------/

# invariant mass of the first reconstructed Z boson Z1rec (according to setting of user_switch M_leplep
# in parameter.dat) regularly binned from 0-200 GeV in 2 GeV steps
distributionname  =  m_Z1
distributiontype  =  m
particle 1        =  Z1rec 1
startpoint        =  0.
endpoint          =  200.
binwidth          =  2.
# NOTE: Z1rec is a process-dependent particle defintion, which is implemented for pp(->ZZ)->4l

# invariant mass of the second reconstructed Z boson Z2rec (according to setting of user_switch M_leplep
# in parameter.dat) regularly binned from 0-200 GeV in 2 GeV steps
distributionname  =  m_Z2
distributiontype  =  m
particle 1        =  Z2rec 1
startpoint        =  0.
endpoint          =  200.
binwidth          =  2.
# NOTE: Z2rec is a process-dependent particle defintion, which is implemented for pp(->ZZ)->4l

# transverse momentum of the sum of emZ1 (electron of the first reconstructed Z boson) and
# epZ2 (positron of the second reconstructed Z boson) regularly binned in 200 bins from 0-1000 GeV (ie, 5 GeV bi
distributionname  =  pT_emZ1epZ2
distributiontype  =  pT
particle 1        =  emZ1 1
particle 1        =  epZ2 1
startpoint        =  0.
endpoint          =  1000.
binnumber         =  200
# NOTE: emZ1 and epZ2 are process-dependent particle defintions, which are implemented for pp(->ZZ)->4l

# transverse momentum of the sum of emZ2 (electron of the second reconstructed Z boson) and
# epZ1 (positron of the first reconstructed Z boson) regularly binned in 200 bins from 0-1000 GeV (ie, 5 GeV bin
distributionname  =  pT_emZ2epZ1
distributiontype  =  pT
particle 1        =  emZ2 1
particle 1        =  epZ1 1
startpoint        =  0.
endpoint          =  1000.
binnumber         =  200
# NOTE: emZ2 and epZ1 are process-dependent particle defintions, which are implemented for pp(->ZZ)->4l

# transverse momentum of hardest Lepton regularly binned in 200 bins from 0-1000 GeV (ie, 5 GeV bins)
distributionname  =  pT_lep1
distributiontype  =  pT
particle 1        =  lep 1
startpoint        =  0.
endpoint          =  1000.
binnumber         =  200
-UU-:----F1  distribution.dat   Top (1,0)      (Fundamental Fld) 4:30PM 10.66 ----------------------------------
Folding buffer... done
```

How to run

- After changing into the run directory we start the run script

```
$  ./bin/run_process
```

- First, choose a name for the run:

```
|===>> run_my_first_ZZ
```

- The MATRIX run shell has many options, eg, modify input files typing:

```
|===>> parameter
|===>> model
|===>> distribution
```

- Now we can start the run, type

```
|===>> run
```

```
[[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX] ./bin/run_process

          /-------------------------------------------------------------------\
          | MATRIX: A fully-differential NNLO(+NNLL) process library          |
          |                                                                   |
          |          __  __    ___    ____    ___    _   _                   |
          |         | _\/_ |   / _ \   |___|  / _ \   ||   \\   //          |
          |         || \/ ||  | |_| |    ||   ||_||   ||    \\ //           |
          |         ||    ||  | ___ |    ||   ||\\    ||    // \\           |
          |         ||    ||  ||   ||    ||   || \\   ||   //   \\          |
          |                                                                   |
          |          Version: 1.0.0.release_candidate4      Aug 2017          |
          |                                                                   |
          | Munich -- the MUlti-chaNnel Integrator at swiss (CH) precision -- |
          | Automates qT-subtraction and Resummation to Integrate X-sections  |
          |                                                                   |
          | \          \ ____      \          \ ____      \ ____      \       |
          |  \          \          |\          \          |\          |\      |
          |   )====  +   )====  +  | )====  +   )====  +  | )====  +  |-)==== |
          |  /          /          |/          /____      |/          |/      |
          | /          /           /          /           /           /       |
          |                                                                   |
          | M. Grazzini                                (grazzini@physik.uzh.ch) |
          | S. Kallweit                               (stefan.kallweit@cern.ch) |
          | M. Wiesemann                             (marius.wiesemann@cern.ch) |
          |-------------------------------------------------------------------|
          | MATRIX is based on a number of different computations and tools   |
          | from various people and groups. Please acknowledge their efforts  |
          | by citing the list of references which is created with every run. |
          \-------------------------------------------------------------------/

<<MATRIX-READ>> Type name of folder for this run (has to start with "run_").
                "ENTER" to create and use "run_01". Press TAB or type "list" to
                show existing runs. Type "exit" or "quit" to stop. Any other
                folder will be created.
[|============>> run_my_first_ZZ
<<MATRIX-READ>> Type one of the following commands: ("TAB" for auto-completion)
--------------------------------------------------------------------------------
General commands    ||   description
--------------------------------------------------------------------------------
help                >>   Show help menu.
help <command>      >>   Show help message for specific <command>.
list                >>   List available commands again.
exit                >>   Stop the code.
quit                >>   Stop the code.
--------------------------------------------------------------------------------
Input to modify     ||   description
--------------------------------------------------------------------------------
parameter           >>   Modify "parameter.dat" input file in editor.
model               >>   Modify "model.dat" input file in editor.
distribution        >>   Modify "distribution.dat" input file in editor.
--------------------------------------------------------------------------------
Run-mode to start   ||   description
--------------------------------------------------------------------------------
run                 >>   Start cross section computation in standard mode.
run_grid            >>   Start only grid setup phase.
run_pre             >>   Start only extrapolation (grid must be already done).
run_pre_and_main    >>   Start after grid setup (grid must be already done).
run_main            >>   Start only main run (other runs must be already done).
run_results         >>   Start only result combination.
run_gnuplot         >>   Start only gnuplotting the results.
setup_run           >>   Setup the run folder, but not start running.
delete_run          >>   Remove run folder (including input/log/result).
tar_run             >>   Create <run_folder>.tar (including input/log/result).
[|============>> parameter
[|============>> model
[|============>> distribution
 |============>> run
```

How to run

- After changing into the run directory we start the run script

```
$  ./bin/run_process
```

- First, choose a name for the run:

```
|===>> run_my_first_ZZ
```

- The MATRIX run shell has many options, eg, modify input files typing:

```
|===>> parameter
```

```
|===>> model
```

```
|===>> distribution
```

- Now we can start the run, type

```
|===>> run
```

- The code goes through all run phases and collects the results at the very end. With default inputs it runs LO with 1% accuracy.

```
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_em1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_Z1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ2epZ1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_Z2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                    /-------------------------------------------------\
                    |                Final result for:                |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC     |
                    \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.815 fb +/- 0.027 fb   (muR, muF unc.:  +6.3%  -7.4%)

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /home/wiesemann/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX/resul
[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX]
```

Running phases

- The running is separated into three main phases, which can be accessed individually by typing "`run_grid`"/"`run_pre`"/"`run_main`" instead of "`run`".
- Each phase requires the previous phases to be successfully done!

```
[|============>> run
<<MATRIX-INFO>> New Run folder created: /home/wiesemann/different-branch-
                munich/MATRIX/run/ppeeexex04_MATRIX/run_my_first_ZZ.
<<MATRIX-INFO>> Using LHAPDF version 6.1.6...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2017-10-16 16:30:15 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:30:20 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:25 | Queued: 0 | Running: 1 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to extrapolate runtimes from accuracy (pre run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:40 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Extrapolating runtimes...
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 1 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |

                    /-------------------------------------------------\
                    |       Preliminary (inaccurate) result for:      |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC     |
                    \-------------------------------------------------/
                 #--------\
                 # LO-run |
                 #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.829 fb +/- 0.042 fb   (muR, muF unc.:  +6.3%  -7.4%)
<MATRIX-RESULT> This result is very inaccurate and only a rough estimate!
<MATRIX-RESULT> Wait until the main run finishes to get the final result!

<<MATRIX-INFO>> Starting cross section computation (main run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
```

Running phases

- The running is separated into three main phases, which can be accessed individually by typing "`run_grid`"/"`run_pre`"/"`run_main`" instead of "`run`".
- Each phase requires the previous phases to be successfully done!
  - warmup ("`run_grid`")
    - generates the integration grids needed for pre and main run.

```
[|============>> run
<<MATRIX-INFO>> New Run folder created: /home/wiesemann/different-branch-
                munich/MATRIX/run/ppeeexex04_MATRIX/run_my_first_ZZ.
<<MATRIX-INFO>> Using LHAPDF version 6.1.6...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2017-10-16 16:30:15 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:30:20 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:25 | Queued: 0 | Running: 1 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to extrapolate runtimes from accuracy (pre run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:40 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Extrapolating runtimes...
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 1 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |

                    /-----------------------------------------------\
                    |       Preliminary (inaccurate) result for:    |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC   |
                    \-----------------------------------------------/
                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.829 fb +/- 0.042 fb   (muR, muF unc.:  +6.3%  -7.4%)
<MATRIX-RESULT> This result is very inaccurate and only a rough estimate!
<MATRIX-RESULT> Wait until the main run finishes to get the final result!

<<MATRIX-INFO>> Starting cross section computation (main run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
```

Running phases

- The running is separated into three main phases, which can be accessed individually by typing "`run_grid`"/"`run_pre`"/"`run_main`" instead of "`run`".
- Each phase requires the previous phases to be successfully done!
  - warmup ("`run_grid`")
    - generates the integration grids needed for pre and main run.
  - runtime extrapolation ("`run_pre`")
    - short test runs to estimate runtime
    - prints preliminary result at the end

```
[|============>> run
<<MATRIX-INFO>> New Run folder created: /home/wiesemann/different-branch-
                munich/MATRIX/run/ppeeexex04_MATRIX/run_my_first_ZZ.
<<MATRIX-INFO>> Using LHAPDF version 6.1.6...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2017-10-16 16:30:15 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:30:20 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:25 | Queued: 0 | Running: 1 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to extrapolate runtimes from accuracy (pre run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:40 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Extrapolating runtimes...
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 1 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |

                    /------------------------------------------------\
                    |       Preliminary (inaccurate) result for:     |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC    |
                    \------------------------------------------------/
                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.829 fb +/- 0.042 fb   (muR, muF unc.:  +6.3%  -7.4%)
<MATRIX-RESULT> This result is very inaccurate and only a rough estimate!
<MATRIX-RESULT> Wait until the main run finishes to get the final result!

<<MATRIX-INFO>> Starting cross section computation (main run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
```

Running phases

- The running is separated into three main phases, which can be accessed individually by typing "`run_grid`"/"`run_pre`"/"`run_main`" instead of "`run`".
- Each phase requires the previous phases to be successfully done!
  - warmup ("`run_grid`")
    - generates the integration grids needed for pre and main run.
  - runtime extrapolation ("`run_pre`")
    - short test runs to estimate runtime
    - prints preliminary result at the end
  - x-section computation ("`run_main`")
    - parallelized by runtime from pre run, `max_time_per_job` and `accuracy`
    - starts result combination+gnuplot

```
[|============>> run
<<MATRIX-INFO>> New Run folder created: /home/wiesemann/different-branch-
                munich/MATRIX/run/ppeeexex04_MATRIX/run_my_first_ZZ.
<<MATRIX-INFO>> Using LHAPDF version 6.1.6...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2017-10-16 16:30:15 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:30:20 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:25 | Queued: 0 | Running: 1 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to extrapolate runtimes from accuracy (pre run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:35 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:40 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Extrapolating runtimes...
<<MATRIX-JOBS>> | 2017-10-16 16:33:45 | Queued: 1 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 0 | Running: 0 | Finished: 1 |

                    /-----------------------------------------------\
                    |       Preliminary (inaccurate) result for:    |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC   |
                    \-----------------------------------------------/
                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.829 fb +/- 0.042 fb   (muR, muF unc.:  +6.3%  -7.4%)
<MATRIX-RESULT> This result is very inaccurate and only a rough estimate!
<MATRIX-RESULT> Wait until the main run finishes to get the final result!

<<MATRIX-INFO>> Starting cross section computation (main run)...
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
```

Running phases

- The running is separated into three main phases, which can be accessed individually by typing "`run_grid`"/"`run_pre`"/"`run_main`" instead of "`run`".
- Each phase requires the previous phases to be successfully done!
  - warmup ("`run_grid`")
    - generates the integration grids needed for pre and main run.
  - runtime extrapolation ("`run_pre`")
    - short test runs to estimate runtime
    - prints preliminary result at the end
  - x-section computation ("`run_main`")
    - parallelized by runtime from pre run, `max_time_per_job` and `accuracy`
    - starts result combination+gnuplot
    - prints final result at the end

```
<<MATRIX-JOBS>> | 2017-10-16 16:33:50 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:33:55 | Queued: 0 | Running: 2 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2017-10-16 16:34:00 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2017-10-16 16:34:05 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: pT_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ1epZ2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_lep1_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: dR_em1_ep1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_lep2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_em1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_Z1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_emZ2epZ1__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: m_Z2__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                    /-------------------------------------------------\
                    |                Final result for:                |
                    |      p p --> e^- e^- e^+ e^+   @ 13 TeV LHC     |
                    \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF30_lo_as_0118
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> LO:      5.815 fb +/- 0.027 fb   (muR, muF unc.:  +6.3%  -7.4%)

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /home/wiesemann/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX/resul
[wiesemann:~/different-branch-munich/MATRIX/run/ppeeexex04_MATRIX]
```

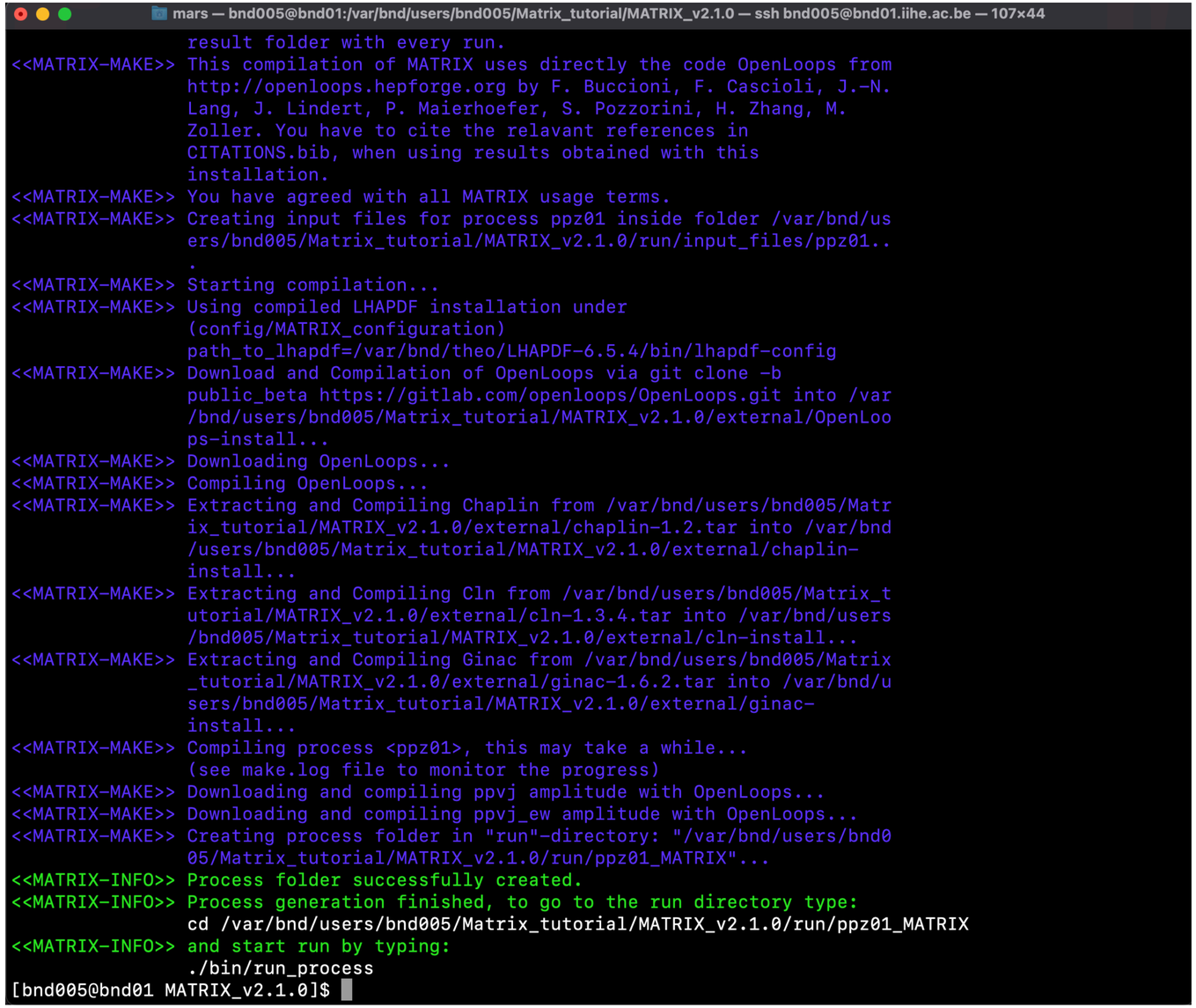
Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
```

task: start runing script & go through interactive shell:
1. give it some name
2. check parameter.dat, model.dat, distribution.dat
3. start run

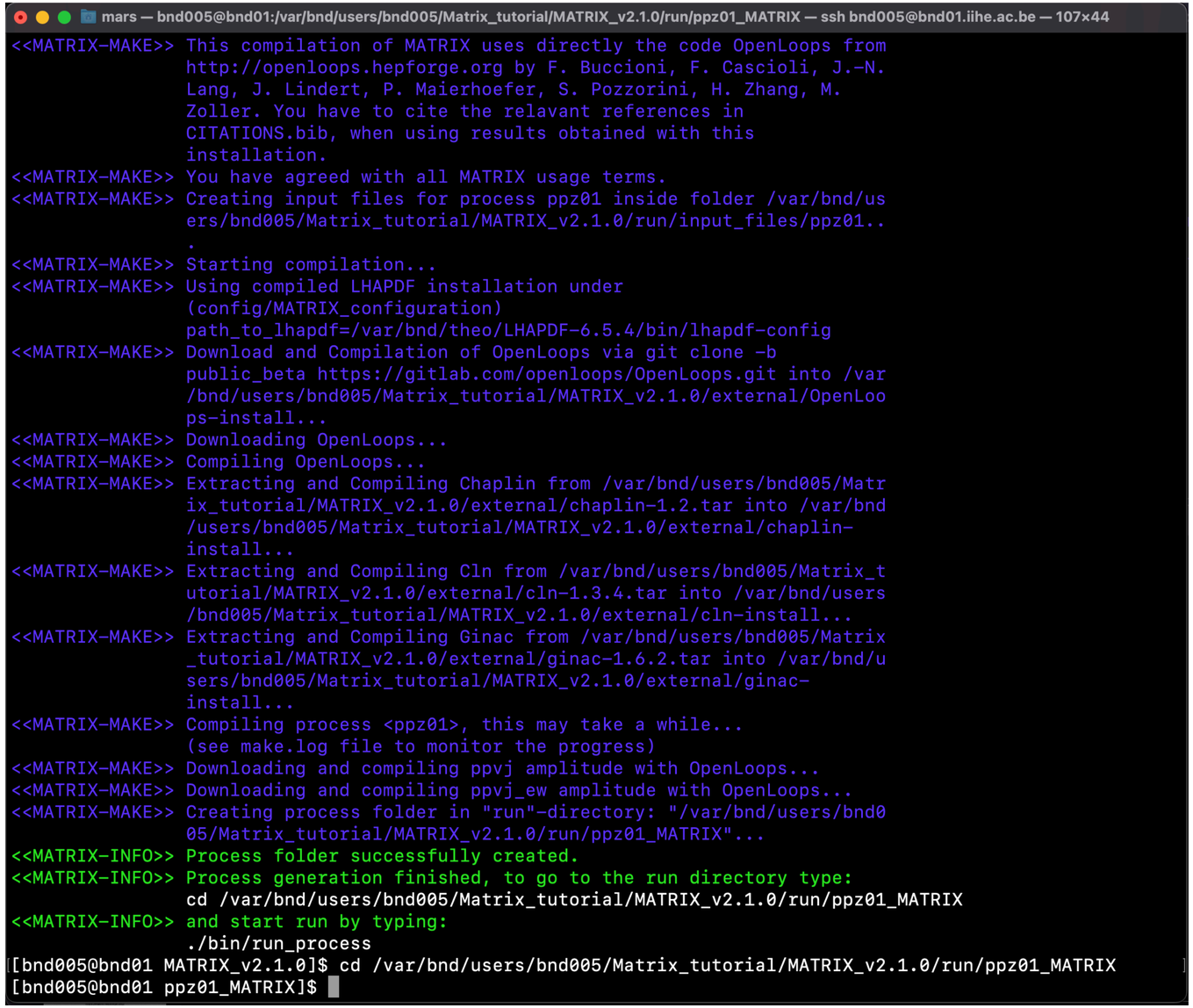
hint: the on-screen output tells you everything you need to know, e.g. set default editor either through **`export`** or **`MATRIX_configuration`**



Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
```



Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
```

Hands on !

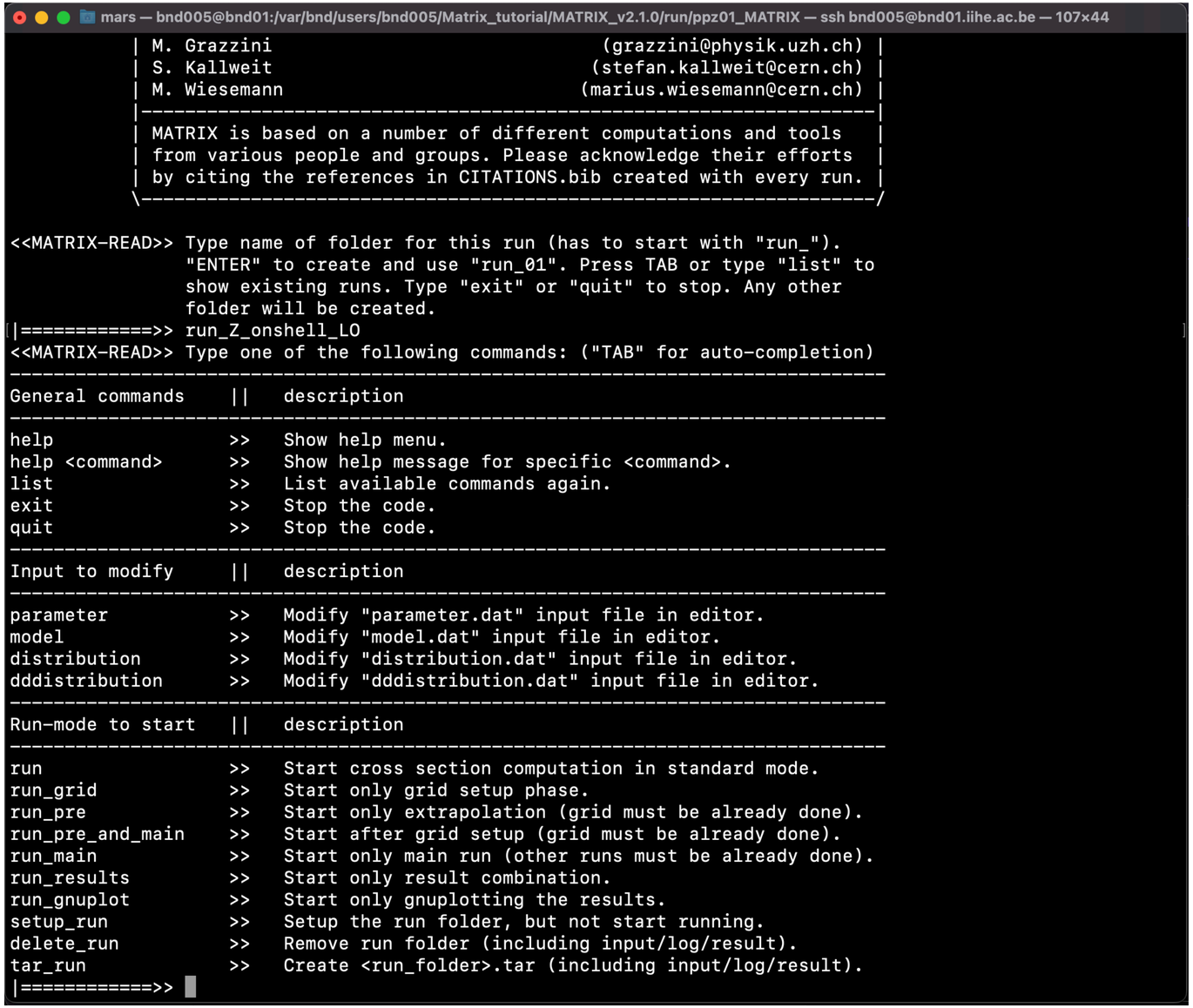
- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO  (choose name)
```

Hands on !

- now go to the run folder we just created through compilation and let's start running

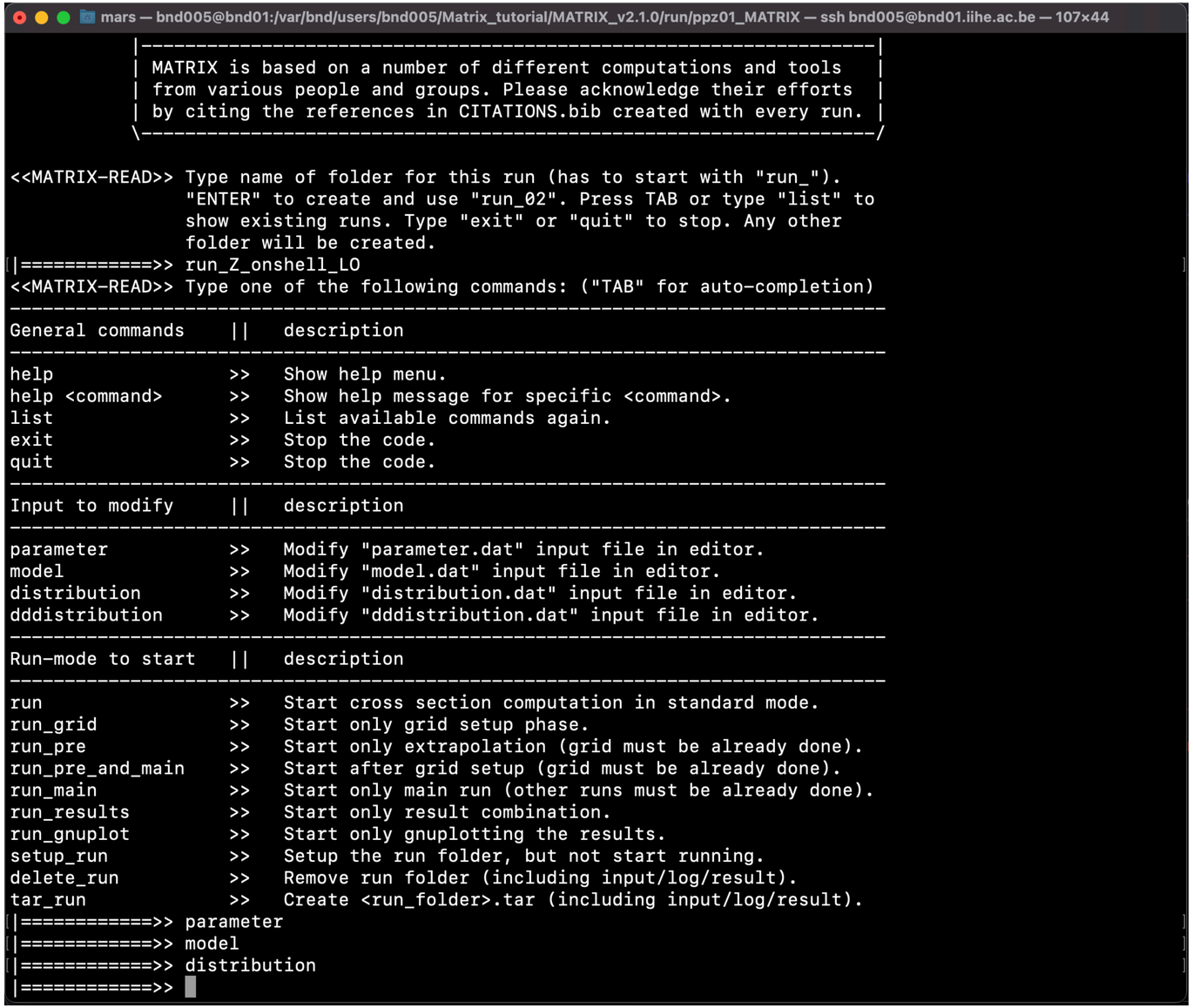
```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
```



Hands on !

- now go to the run folder we just created through compilation and let's start running

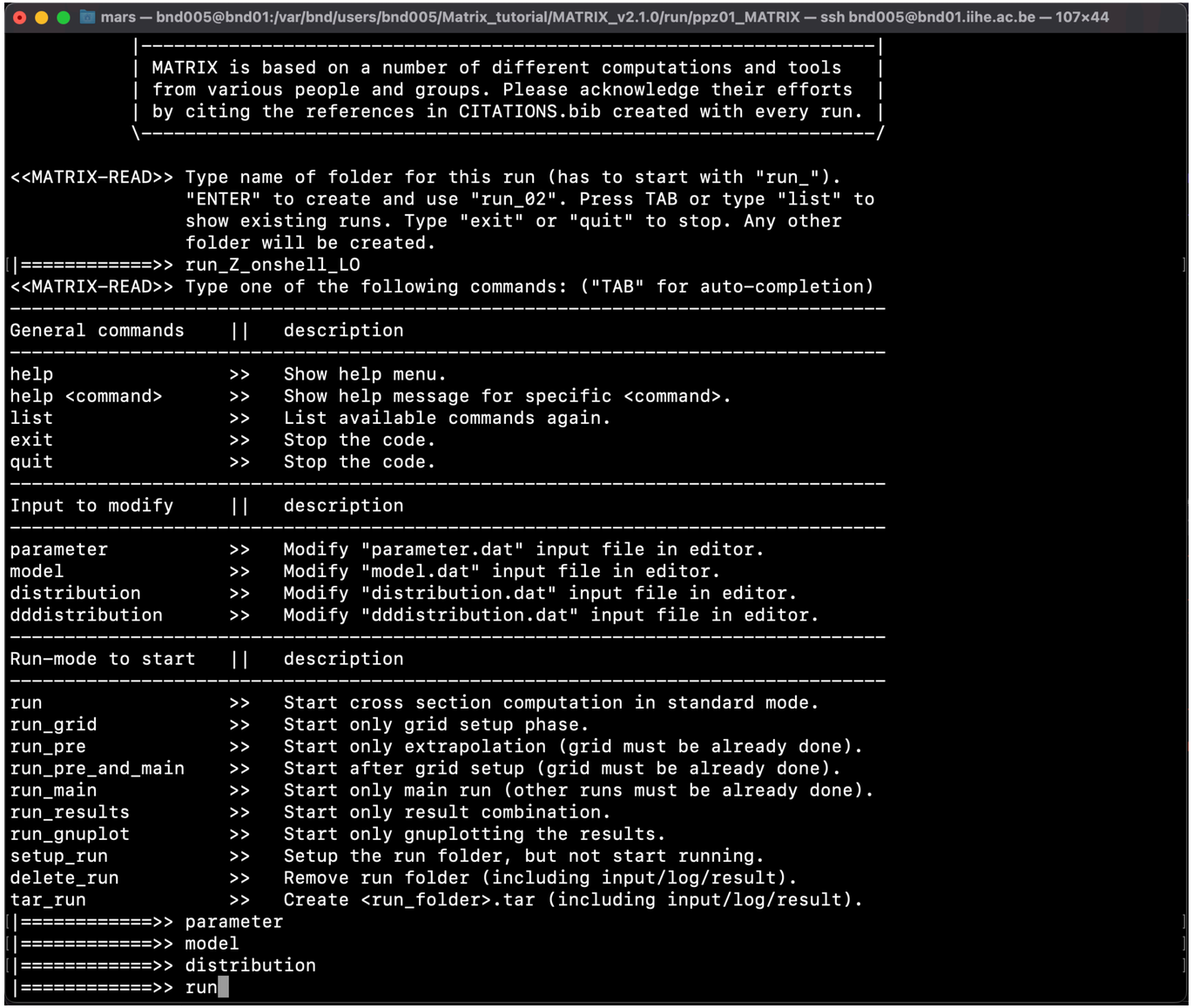
```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
```



Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
> run
```

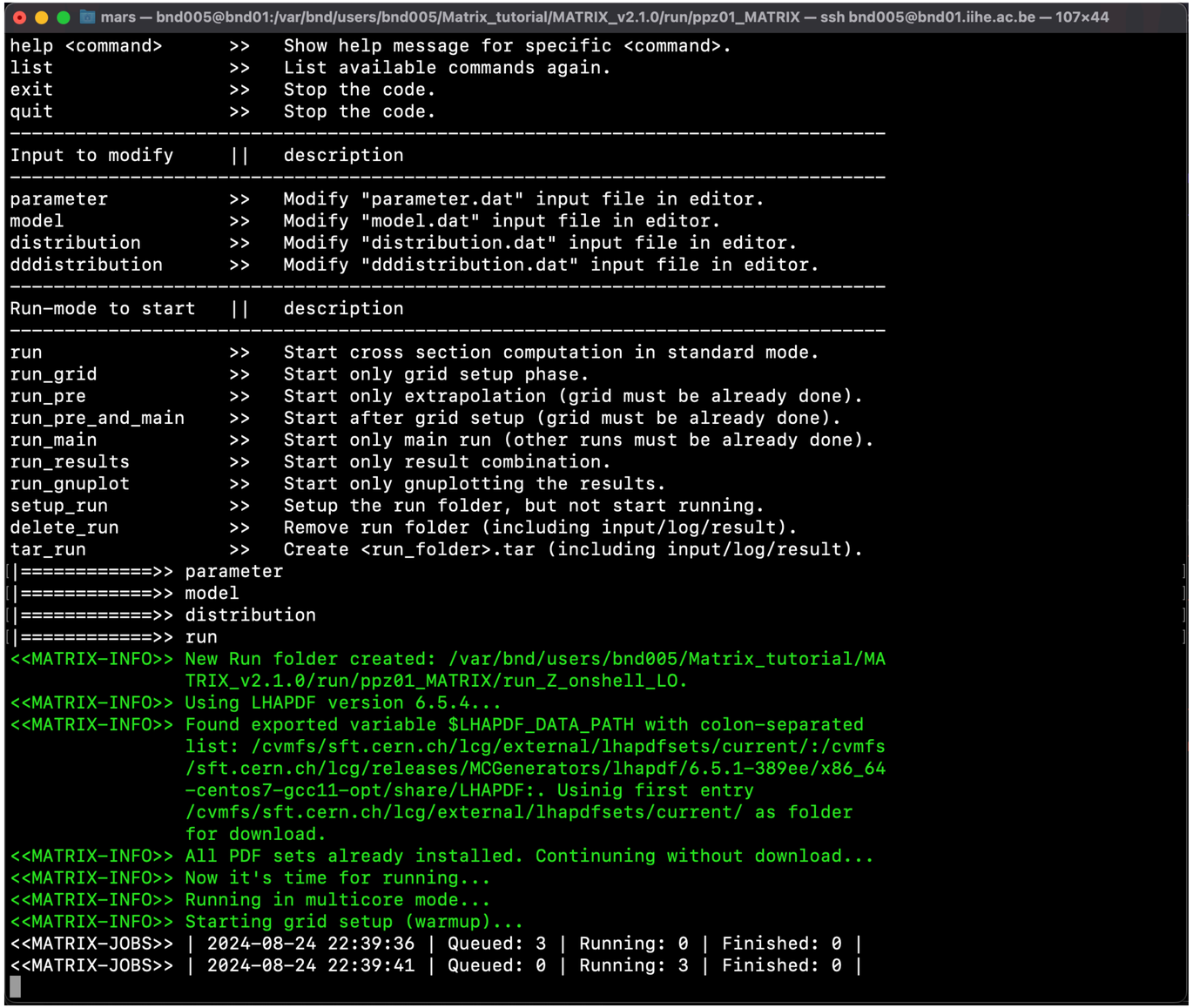


Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
> run
```

warmup: *generation of integration grids*



Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
> run
```

warmup: *generation of integration grids*

pre-run: *estimate of runtime (short runs)*

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44
parameter           >>   Modify "parameter.dat" input file in editor.
model               >>   Modify "model.dat" input file in editor.
distribution        >>   Modify "distribution.dat" input file in editor.
dddistribution      >>   Modify "dddistribution.dat" input file in editor.
-------------------------------------------------------------------------------
Run-mode to start   ||   description
-------------------------------------------------------------------------------
run                 >>   Start cross section computation in standard mode.
run_grid            >>   Start only grid setup phase.
run_pre             >>   Start only extrapolation (grid must be already done).
run_pre_and_main    >>   Start after grid setup (grid must be already done).
run_main            >>   Start only main run (other runs must be already done).
run_results         >>   Start only result combination.
run_gnuplot         >>   Start only gnuplotting the results.
setup_run           >>   Setup the run folder, but not start running.
delete_run          >>   Remove run folder (including input/log/result).
tar_run             >>   Create <run_folder>.tar (including input/log/result).
|============>> parameter
|============>> model
|============>> distribution
|============>> run
<<MATRIX-INFO>> New Run folder created: /var/bnd/users/bnd005/Matrix_tutorial/MA
                TRIX_v2.1.0/run/ppz01_MATRIX/run_01.
<<MATRIX-INFO>> Using LHAPDF version 6.5.4...
<<MATRIX-INFO>> Found exported variable $LHAPDF_DATA_PATH with colon-separated
                list: /cvmfs/sft.cern.ch/lcg/external/lhapdfsets/current/:/cvmfs
                /sft.cern.ch/lcg/releases/MCGenerators/lhapdf/6.5.1-389ee/x86_64
                -centos7-gcc11-opt/share/LHAPDF:. Usinig first entry
                /cvmfs/sft.cern.ch/lcg/external/lhapdfsets/current/ as folder
                for download.
<<MATRIX-INFO>> All PDF sets already installed. Continuning without download...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2024-08-24 22:32:28 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:32:33 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:35:58 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to determine runtimes (pre run)...
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:08 | Queued: 0 | Running: 3 | Finished: 0 |
```

Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
> run
```

warmup: *generation of integration grids*

pre-run: *estimate of runtime (short runs)*

main-run: *computation of cross sections*

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44
               for download.
<<MATRIX-INFO>> All PDF sets already installed. Continuning without download...
<<MATRIX-INFO>> Now it's time for running...
<<MATRIX-INFO>> Running in multicore mode...
<<MATRIX-INFO>> Starting grid setup (warmup)...
<<MATRIX-JOBS>> | 2024-08-24 22:32:28 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:32:33 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:35:58 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Starting runs to determine runtimes (pre run)...
<<MATRIX-JOBS>> | 2024-08-24 22:36:03 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:08 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:23 | Queued: 0 | Running: 1 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:28 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:28 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Extrapolating runtimes...
<<MATRIX-JOBS>> | 2024-08-24 22:36:28 | Queued: 1 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:33 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:33 | Queued: 0 | Running: 0 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:33 | Queued: 0 | Running: 0 | Finished: 1 |

                  /-------------------------------------------------\
                  |              Pre-run result for:                |
                  |            p p --> Z   @ 13 TeV LHC             |
                  \-------------------------------------------------/

               #--------\
               # LO-run |
               #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.911e+07 fb +/- 1.8e+05 fb (muR, muF unc.: +11.4% -12.4%)
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> This result is very inaccurate and only a rough estimate!
<MATRIX-RESULT> Wait until the main run finishes to get the final result!

<<MATRIX-INFO>> Starting cross section computation (main run)...
<<MATRIX-JOBS>> | 2024-08-24 22:36:33 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:36:38 | Queued: 0 | Running: 3 | Finished: 0 |
```

Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO (choose name)
> parameter/model/distribution
> run
```

warmup: *generation of integration grids*

pre-run: *estimate of runtime (short runs)*

main-run: *computation of cross sections*

final result: $\sigma(pp \to Z) = 49.1(1)^{+11.4\%}_{-12.5\%}\,\text{nb}$

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 22:43:41 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:43:46 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:01 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |                Final result for:                |
                  |             p p --> Z   @ 13 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```

Hands on !

- now go to the run folder we just created through compilation and let's start running

```
$ cd run/ppz01_MATRIX
$ ./bin/run_process
> run_Z_onshell_LO  (choose name)
```

Again you have a solution to this task in form of a bash file that you can just execute (inside the **MATRIX_v2.1.0/run/ppz01_MATRIX** folder) from here:

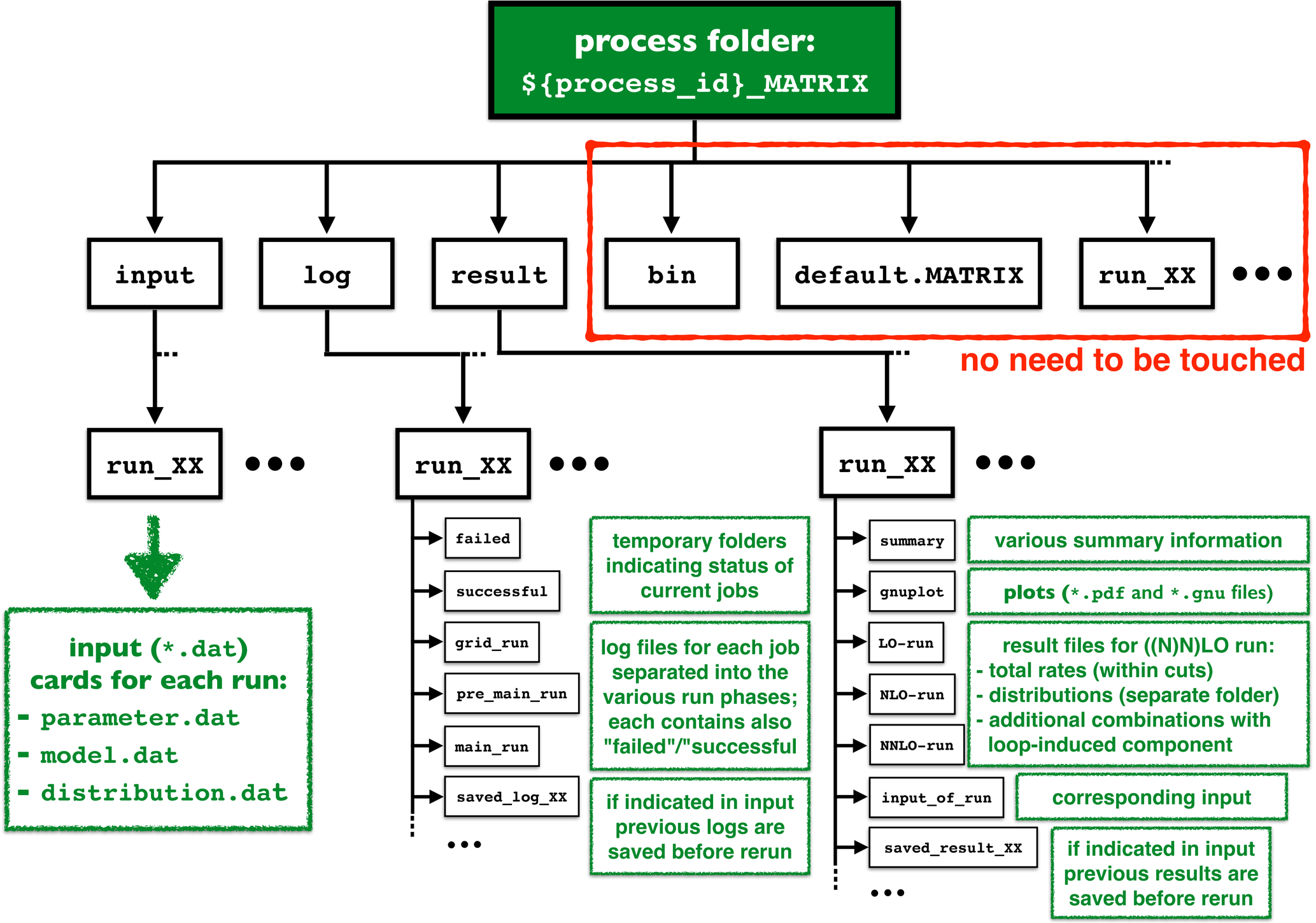
/var/bnd/theo/help/solution-2-running.sh

pre-run: *estimate of runtime (short runs)*

main-run: *computation of cross sections*

final result: $\sigma(pp \to Z) = 49.1(1)^{+11.4\%}_{-12.5\%}\,\text{nb}$

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 22:43:41 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:43:46 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:01 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
                    |           p p --> Z    @ 13 TeV LHC           |
                    \--------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```


process folder:
${process_id}_MATRIX
input
log
result
bin
default.MATRIX
run_XX
no need to be touched
run_XX
run_XX
run_XX
input (*.dat)
cards for each run:
- parameter.dat
- model.dat
- distribution.dat
failed
successful
grid_run
pre_main_run
main_run
saved_log_XX
temporary folders indicating status of current jobs
log files for each job separated into the various run phases; each contains also "failed"/"successful
if indicated in input previous logs are saved before rerun
summary
gnuplot
LO-run
NLO-run
NNLO-run
input_of_run
saved_result_XX
various summary information
plots (*.pdf and *.gnu files)
result files for ((N)N)LO run:
- total rates (within cuts)
- distributions (separate folder)
- additional combinations with loop-induced component
corresponding input
if indicated in input previous results are saved before rerun

Hands on !

- let's checkout the run and the results we just created

task: investigate folder structure; go to result folder, find summary on-screen output, find used inputs, find integrated cross section (rates), find distributions, …

question: look at Z p_T spectrum; why does it look so weird? (only first bin filled)

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO — ssh bnd005@bnd01.iihe.a...
<<MATRIX-JOBS>> | 2024-08-24 22:44:01 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |               Final result for:                 |
                  |            p p --> Z   @ 13 TeV LHC             |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_L
O
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/
[bnd005@bnd01 run_Z_onshell_LO]$
```

- let
jus

ta

question: look at Z p_T spectrum;
why does it look so weird?
(only first bin filled)

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 152×25

```
File Edit Options Buffers Tools Help
#  left-edge  right-edge       scale-central  central-error       scale-min      min-error       scale-max      max-error      rel-down      rel-up
          0           5           5726920.0       5427.42       5180883.7        4900.48       6203723.7        5892.52        -9.53%       8.33%
          5          10                   0             0               0              0               0              0            0%          0%
         10          15                   0             0               0              0               0              0            0%          0%
         15          20                   0             0               0              0               0              0            0%          0%
         20          25                   0             0               0              0               0              0            0%          0%
         25          30                   0             0               0              0               0              0            0%          0%
         30          35                   0             0               0              0               0              0            0%          0%
         35          40                   0             0               0              0               0              0            0%          0%
         40          45                   0             0               0              0               0              0            0%          0%
         45          50                   0             0               0              0               0              0            0%          0%
         50          55                   0             0               0              0               0              0            0%          0%
         55          60                   0             0               0              0               0              0            0%          0%
         60          65                   0             0               0              0               0              0            0%          0%
         65          70                   0             0               0              0               0              0            0%          0%
         70          75                   0             0               0              0               0              0            0%          0%
         75          80                   0             0               0              0               0              0            0%          0%
         80          85                   0             0               0              0               0              0            0%          0%
         85          90                   0             0               0              0               0              0            0%          0%
         90          95                   0             0               0              0               0              0            0%          0%
         95         100                   0             0               0              0               0              0            0%          0%
        100         105                   0             0               0              0               0              0            0%          0%
-UU-:----F1  pT_Z__LO.dat    Top L1     (Fundamental) ----------------------------------------------------------------------------------------------------
For information about GNU Emacs and the GNU system, type C-h C-a.
```

```
                    |              Final result for:                |
                    |            p p --> Z   @ 13 TeV LHC           |
                    \-----------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                  #--------\
                  # LO-run |
                  #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_L
O
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/
[bnd005@bnd01 run_Z_onshell_LO]$
```

Additional information/hidden features

- many additional command-line options, use "`-h`" to show all options

`./matrix -h`

MATRIX — -bash — 86×44

```
[mars:~/Uni/Own_Codes/publish_MATRIX_v2.1.0/MATRIX] ./matrix -h
usage: matrix [-h] [--clean_process] [--install_openloops] [--agree_to_all]
              [--folder_name_extension FOLDER_NAME_EXTENSION] [--no_compile]
              [--old_ginac] [--new_ginac]
              [<process>]

MATRIX.

positional arguments:
  <process>             process name, choose from list ['pph21', 'ppz01',
                        'ppw01', 'ppwx01', 'ppeex02', 'ppnenex02', 'ppenex02',
                        'ppexne02', 'ppaa02', 'ppeexa03', 'ppnenexa03',
                        'ppenexa03', 'ppexnea03', 'ppzz02', 'ppwxw02',
                        'ppemexmx04', 'ppeeexex04', 'ppeexnmnmx04',
                        'ppemxnmnex04', 'ppeexnenex04', 'ppemexnmx04',
                        'ppeeexnex04', 'ppeexmxnm04', 'ppeexexne04',
                        'ppttx20', 'ppaaa03']

optional arguments:
  -h, --help            show this help message and exit
  --clean_process       Clean the selected process completely before compiling
                        it.
  --install_openloops   Force installation of OpenLoops, even though openloops
                        exectuable is found under environmental $PATH variable
                        or path_to_openloops is given in MATRIX_configuration.
  --agree_to_all        Agree to cite properly all external Codes and
                        automatically skip the licence-agreement dialog.
  --folder_name_extension FOLDER_NAME_EXTENSION
                        Specify an extension for the name of the process
                        folder (ie, <process>+"folder_name_extension",
                        default: <process>+"_MATRIX)"
  --no_compile          Do the process setup (including download/compilation
                        of all external tools), but do not (re-)compile the
                        C++ Code.
  --old_ginac           Compile with Ginac version 1.6.2 (default).
  --new_ginac           Compile with newer Ginac version 1.7.8.
[mars:~/Uni/Own_Codes/publish_MATRIX_v2.1.0/MATRIX]
```

`./bin/run_process -h`

Own_Codes — ssh wieseman@th318a.mpp.mpg.de — 86×43

```
[wieseman:~/MATRIX_v2_TNG_VVV/MATRIX/run/ppeex02_MATRIX] ./bin/run_process -h
usage: run_process [-h] [--input_dir INPUT_DIR] [--run_mode RUN_MODE]
                   [--delete_run] [--setup_run] [--tar_run]
                   [--change_name_to NEW_NAME] [--copy_run_from EXISTING_RUN]
                   [-c]
                   [<run folder>]

MATRIX.

positional arguments:
  <run folder>          run folder, must start with run_

optional arguments:
  -h, --help            show this help message and exit
  --input_dir INPUT_DIR
                        Specify directory inside input folder from where
                        template MATRIX input files are taken (default: use
                        "default.input.MATRIX" folder)
  --run_mode RUN_MODE   Specify run mode (RUN_MODE="run"/"run_grid"/"run_pre"/
                        "run_pre_and_main"/"run_result"/"run_gnuplot")
  --delete_run          Remove run folder (including input/log/result).
  --setup_run           Setup the run folder, but not start running.
  --tar_run             Create .tar archive of run folder (including
                        input/log/result).
  --change_name_to NEW_NAME
                        Rename run folder (including input/log/result).
  --copy_run_from EXISTING_RUN
                        Copy run folder from existing run (including
                        input/log/result).
  -c, --continue        Continue the previous run from the specified run_mode;
                        important: make sure the inputs are consistent!
[wieseman:~/MATRIX_v2_TNG_VVV/MATRIX/run/ppeex02_MATRIX]
```

Additional information/hidden features

- many additional command-line options, use "`-h`" to show all options
- most useful arguments:

  `--agree_to_all:` `./matrix ppz01 --agree_to_all`

  ➔ no need to keep typing "y" for the user agreement

  `--clean_process:` `./matrix ppz01 --clean_process`

  ➔ cleans C++ compilation before recompiling (except slow 2-loop amplitude)

Additional information/hidden features

- many additional command-line options, use "`-h`" to show all options
- most useful arguments:

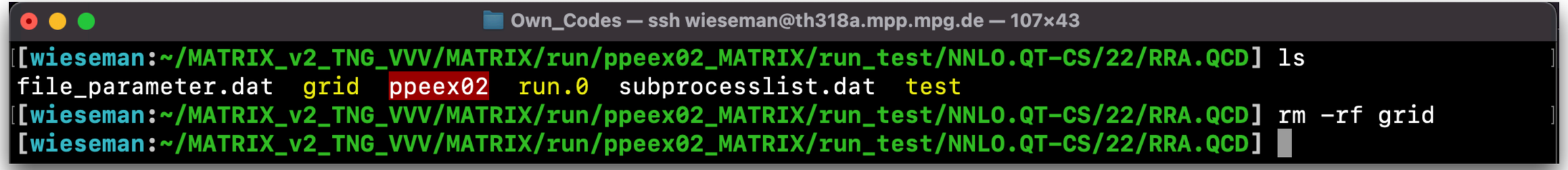
  `--run_mode ${XX}:` `./bin/run_process run_xx --run_mode run_pre_and_main`

  ➔ no need to keep typing "y" for the user agreement

  `--continue:` `./bin/run_process run_xx --run_mode run_grid --continue`

  ➔ continue run that has crashed (jobs without "final result" in execution file)

  ➔ or rerun part of calculation (e.g. after a fix), just delete folders to be redone:



Additional information/hidden features

- many additional command-line options, use "`-h`" to show all options
- most useful arguments
- use the code completely without using the shells (I suggest to use a screen or tmux session):

```
./matrix ppz01 --agree_to_all
./bin/run_process run_xx --run_mode run
```

alternatively run in background (not my recommendation):

```
nohup ./bin/run_process run_xx --run_mode run > f.out &
```

Hands on !

- now let's start playing with the inputs…

task: increase num. precision of our run from 1% (default) to 0.1%

tip: don't create a new run, use the old run and just rerun the main run

tip: you can change the input file directly inside the folder `input/run_XX/parameter.dat` (or use again the interface)

tip: via run mode `run_main` you can restart just the main run (either inline or via interface)

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 22:43:41 | Queued: 3 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:43:46 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:01 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 22:44:06 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 22:44:11 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |                Final result for:                |
                  |             p p --> Z   @ 13 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```

Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
```

Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> precision_LO = 1.e-3
```

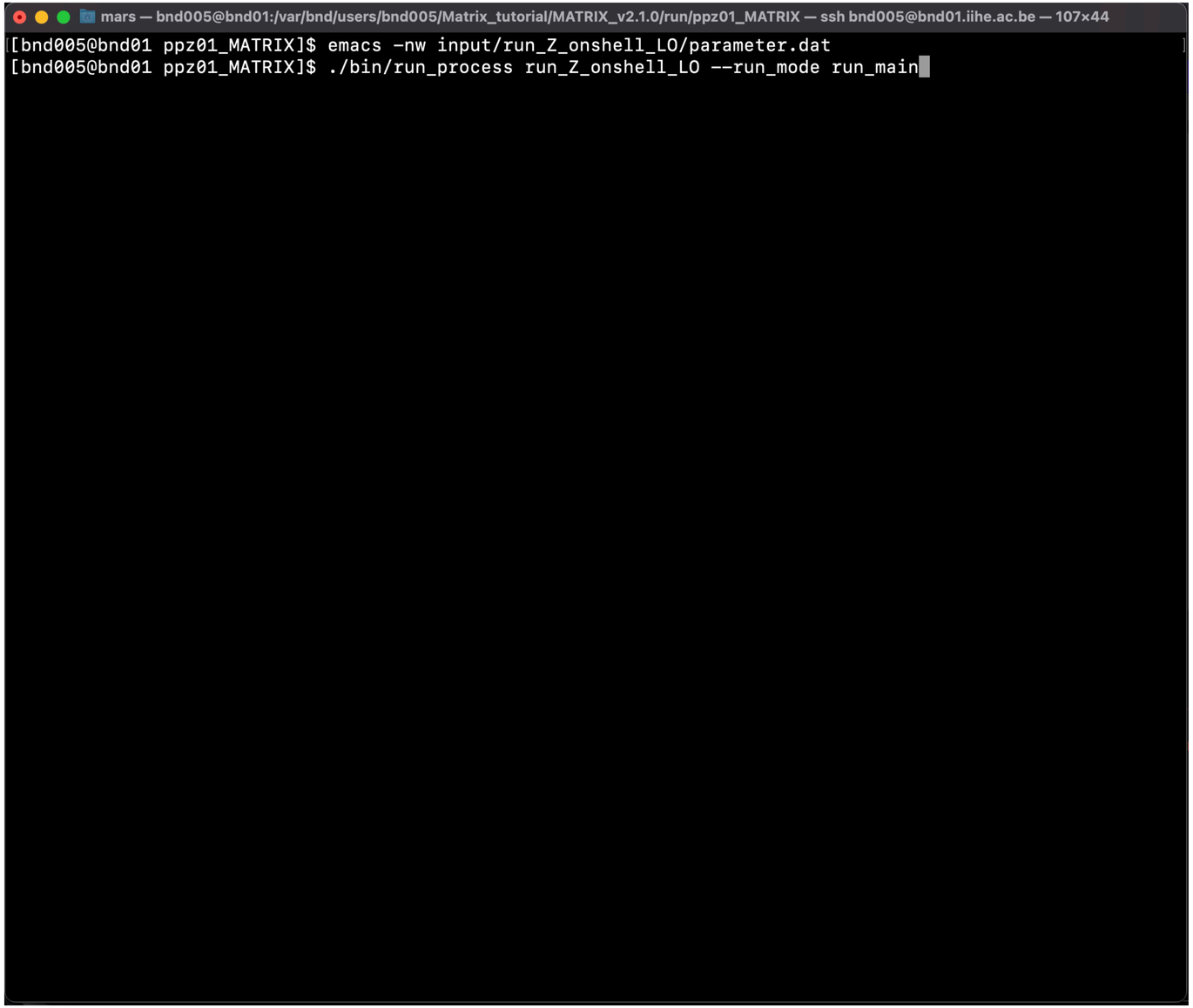
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44

```
File Edit Options Buffers Tools Help
dynamic_scale     =  0          #  dynamic ren./fac. scale
                                #  0: fixed scale above
                                #  1: invariant mass (Q) of system (of the colourless final states)
                                #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final st\
ates)
factor_central_scale = 1        #  relative factor for central scale (important for dynamic scales)
scale_variation   =  1          #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-p\
oint variation
variation_factor  =  2          #  symmetric variation factor; usually a factor of 2 up and down (default)


#-----------------------------\
# Order-dependent run settings |
#-----------------------------/
# LO-run
run_LO            =  1          #  switch for LO cross section (1) on; (0) off
LHAPDF_LO         =  NNPDF31_nlo_as_0118_luxqed  #  LO LHAPDF set
PDFsubset_LO      =  0          #  member of LO PDF set
precision_LO      =  1.e-3      #  precision of LO cross section

# NLO-run
run_NLO_QCD       =  0          #  switch for NLO QCD cross section (1) on; (0) off
run_NLO_EW        =  0          #  switch for NLO EW cross section (1) on; (0) off
LHAPDF_NLO        =  NNPDF31_nlo_as_0118_luxqed  #  NLO LHAPDF set
PDFsubset_NLO     =  0          #  member of NLO PDF set
precision_NLO_QCD =  1.e-2      #  precision of NLO QCD cross section
precision_NLO_EW  =  1.e-2      #  precision of NLO EW correction
NLO_subtraction_method = 1      #  switch to use (2) qT subtraction (1) Catani-Seymour at NLO

# NNLO-run
run_NNLO_QCD      =  0          #  switch for NNLO QCD cross section (1) on; (0) off
add_NLO_EW        =  0          #  switch to add NLO EW cross section to NNLO run (1) on; (0) off
                                #  note: can be added only if also running NNLO
LHAPDF_NNLO       =  NNPDF31_nnlo_as_0118_luxqed  #  NNLO LHAPDF set
PDFsubset_NNLO    =  0          #  member of NNLO PDF set
precision_NNLO_QCD =  1.e-2     #  precision of NNLO QCD cross section
precision_added_EW =  1.e-2     #  precision of NLO EW correction in NNLO run
power_corrections  =  0         #  switch to include leading power corrections in qT-subtraction through re\
coil
                                #  (not recommended for processes involving photons and heavy quarks)
power_corrections_pT0 = 25.     #  characteristic transverse momentum pT0 used to optimise the generation
-UU-:----F1  parameter.dat   12% L36    (Fundamental) ----------------------------------------------------
```

Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> precision_LO = 1.e-3
$ ./bin/run_process run_XX
  --run_mode run_main
```



Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> precision_LO = 1.e-3
$ ./bin/run_process run_XX
  --run_mode run_main
```

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 23:03:40 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:00 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:15 | Queued: 0 | Running: 1 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |                Final result for:                |
                  |             p p --> Z   @ 13 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.927e+07 fb +/- 4.7e+04 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```

Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> precision_LO = 1.e-3
$ ./bin/run_process run_XX
  --run_mode run_main
```

previous result with 1% precision:

```
                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------
```

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 23:03:40 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:00 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:15 | Queued: 0 | Running: 1 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |                Final result for:                |
                  |             p p --> Z   @ 13 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.927e+07 fb +/- 4.7e+04 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```

Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> precision_LO = 1.e-3
```

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 108×44
<<MATRIX-JOBS>> | 2024-08-24 23:03:40 | Queued: 0 | Running: 3 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:00 | Queued: 0 | Running: 2 | Finished: 1 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:15 | Queued: 0 | Running: 1 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-24 23:04:25 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-24 23:04:30 | Queued: 0 | Running: 0 | Finished: 2 |
```

If you did not manage to do so, you the solution to this task also here:

`/var/bnd/theo/help/solution-3-running_with_higher_precision.sh`

(execute inside the **`MATRIX_v2.1.0/run/ppz01_MATRIX`** folder)

previous result with 1% precision:

```
                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.912e+07 fb +/- 1.3e+05 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------
```

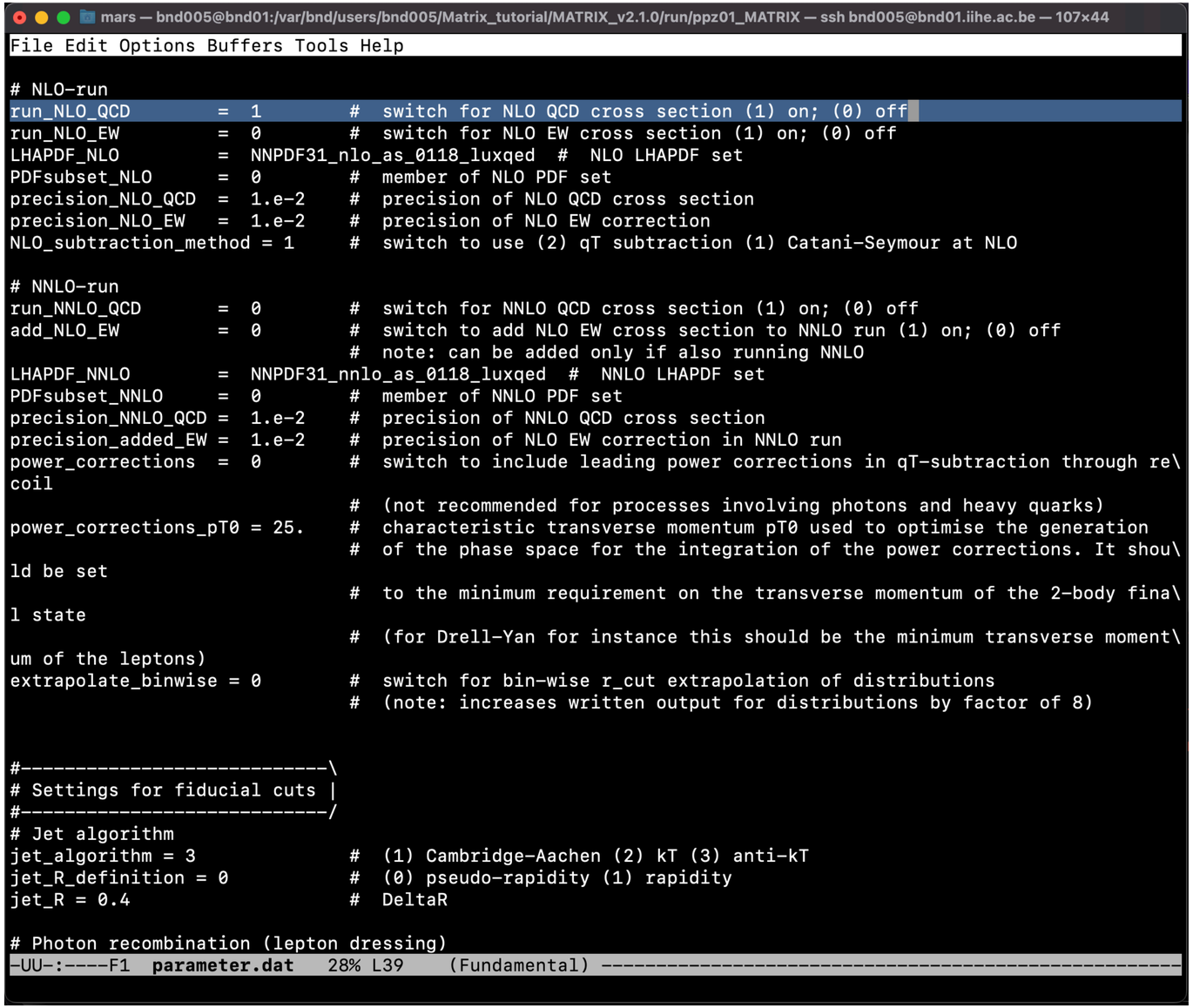
```
                  /-------------------------------------------------\
                  |                Final result for:                |
                  |             p p --> Z   @ 13 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:4.927e+07 fb +/- 4.7e+04 fb (muR, muF unc.: +11.4% -12.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO
[bnd005@bnd01 ppz01_MATRIX]$
```

Hands on !

- now let's start playing with the inputs…

task: start a new run where you turn on NLO and see how the number of jobs changes, repeat this for NNLO (also include NLO EW)

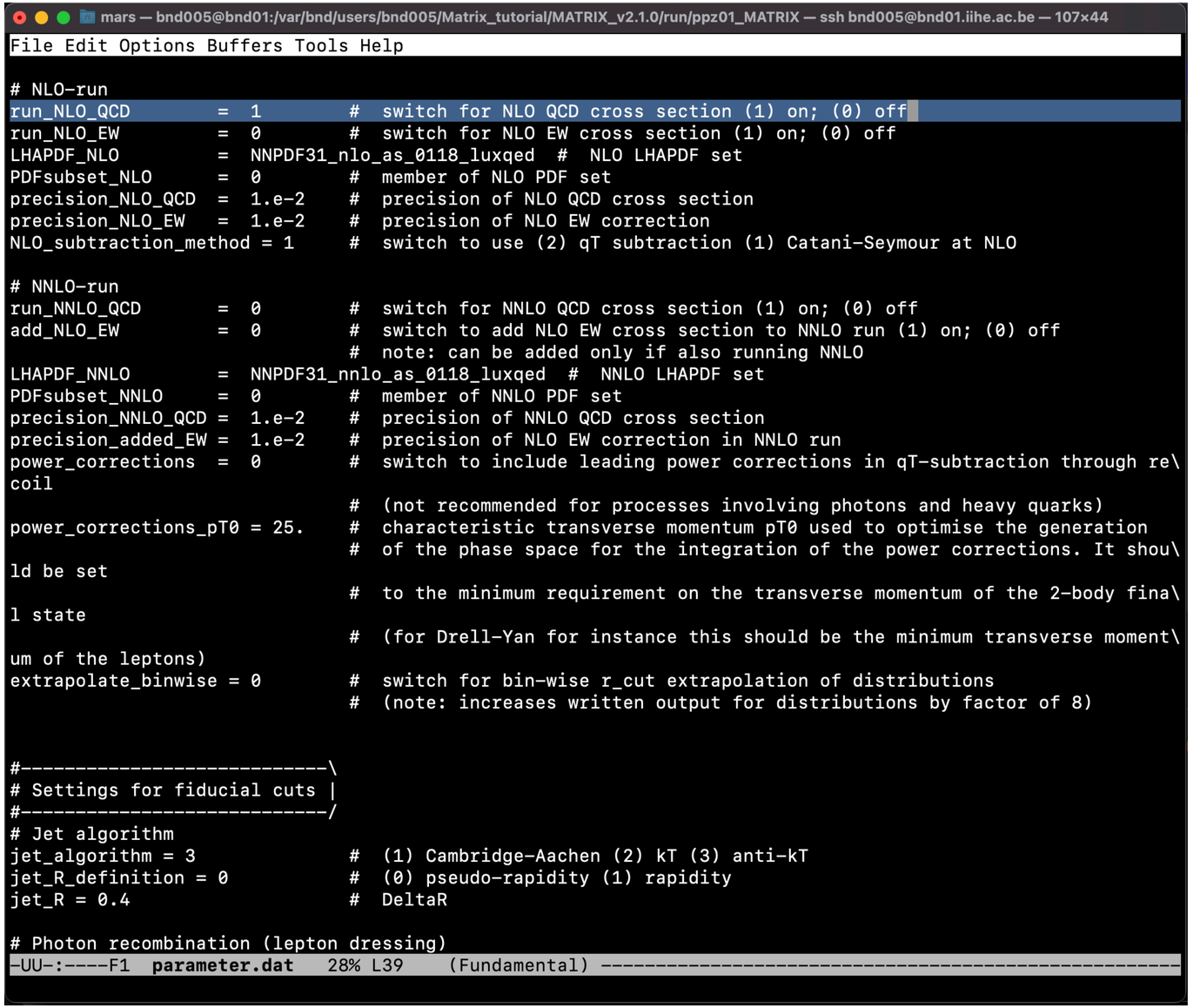
tip: abort run with **`ctrl-c`** (no point of waiting, it will take too long)



Hands on !

- now let's start playing with the inputs…

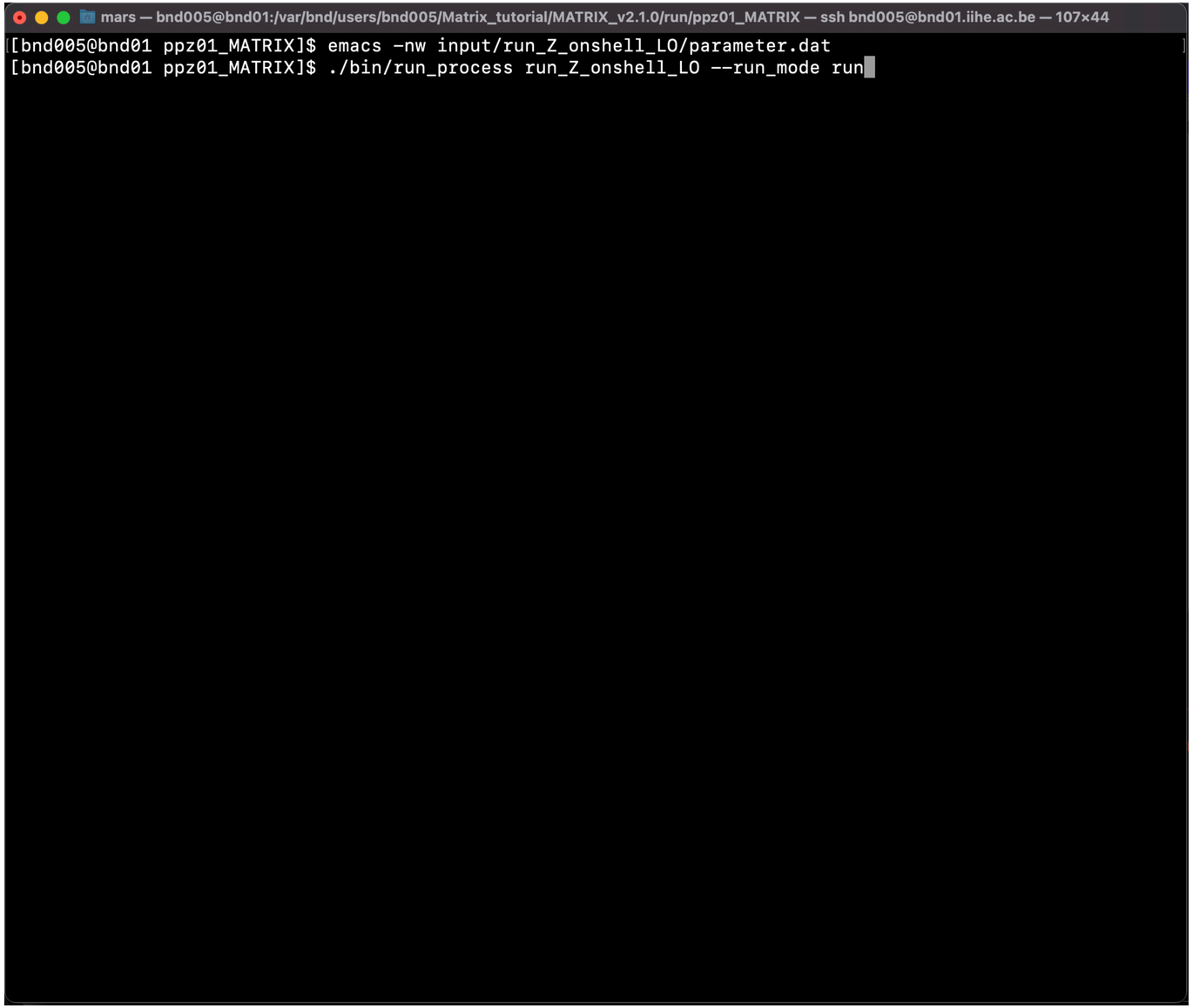
```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NLO_QCD = 1
```



Hands on !

- now let's start playing with the inputs…

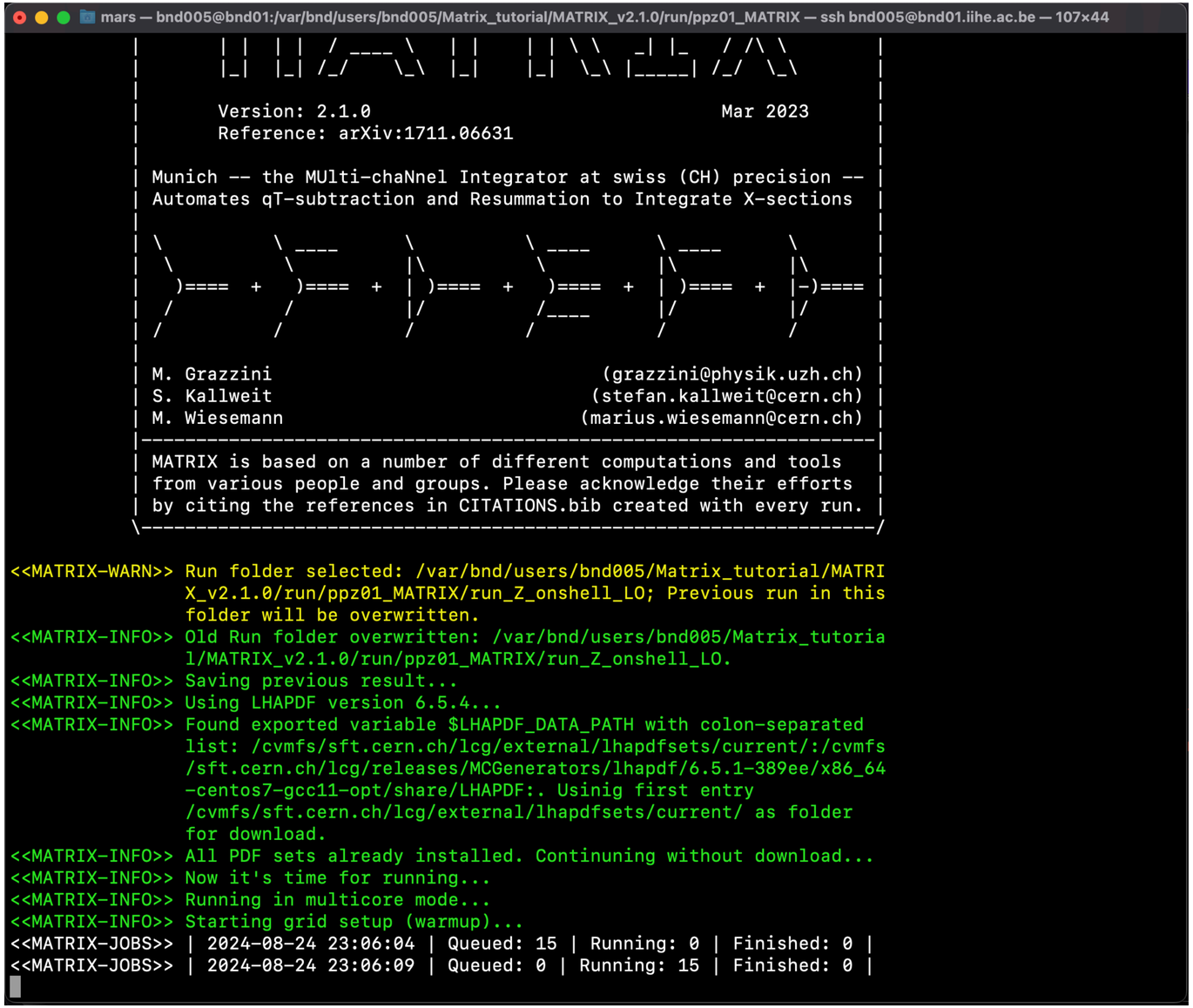
```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NLO_QCD = 1
$ ./bin/run_process run_XX
  --run_mode run
```



Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NLO_QCD = 1
$ ./bin/run_process run_XX
  --run_mode run
```

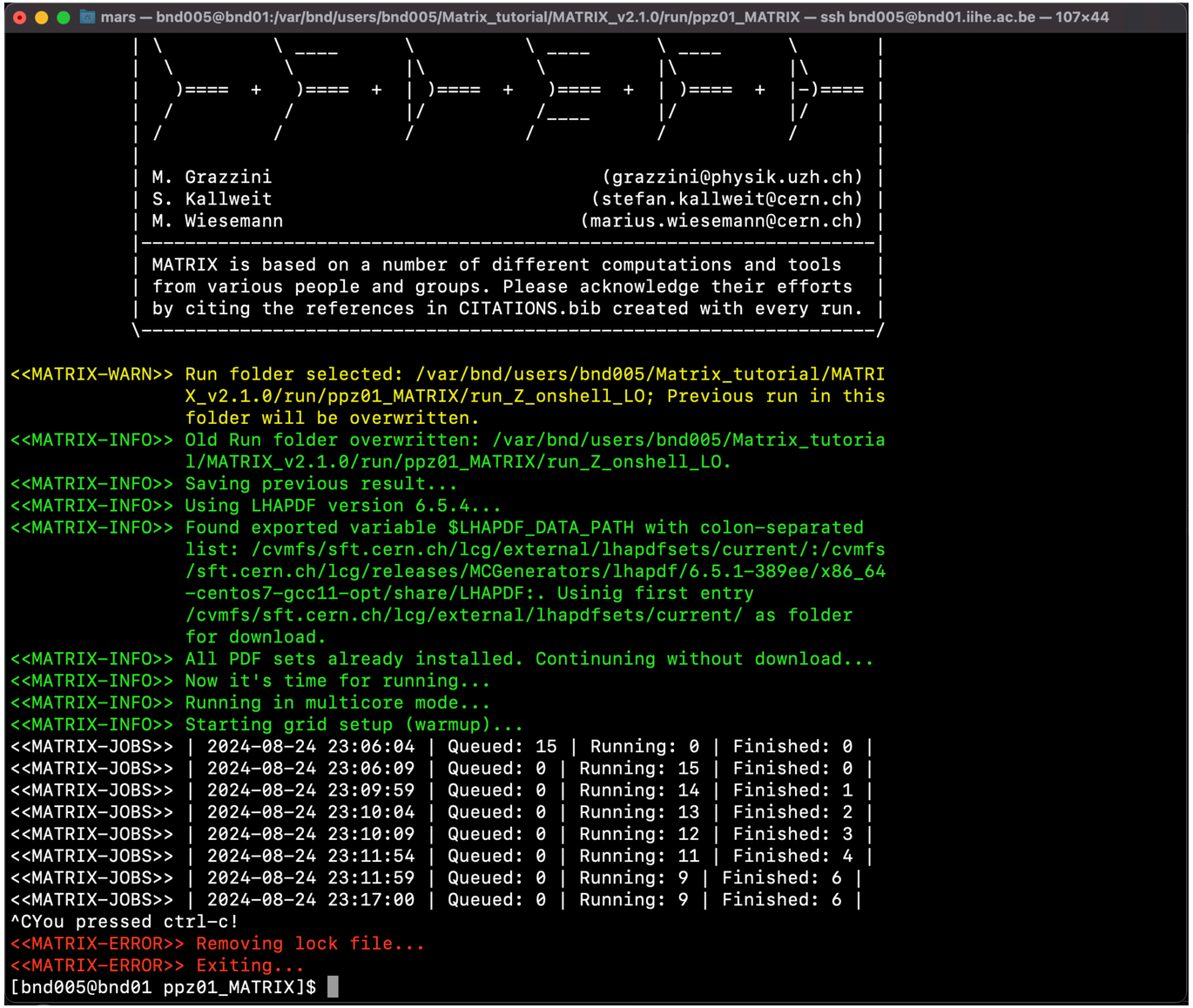


Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NLO_QCD = 1
$ ./bin/run_process run_XX
  --run_mode run
```

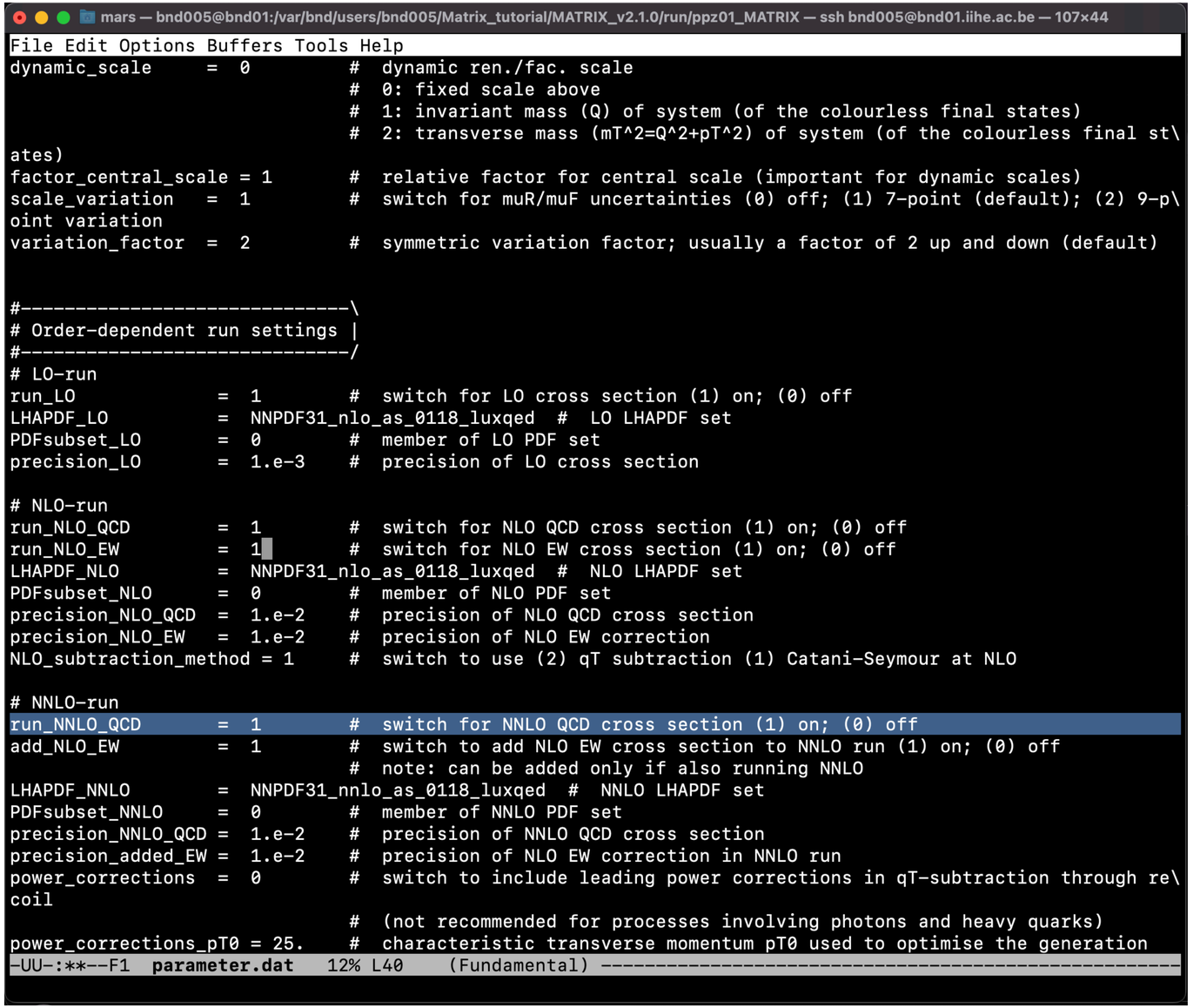
> `ctrl-c` (to stop the code)



Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NNLO_QCD = 1
> add_NLO_EW = 1
```

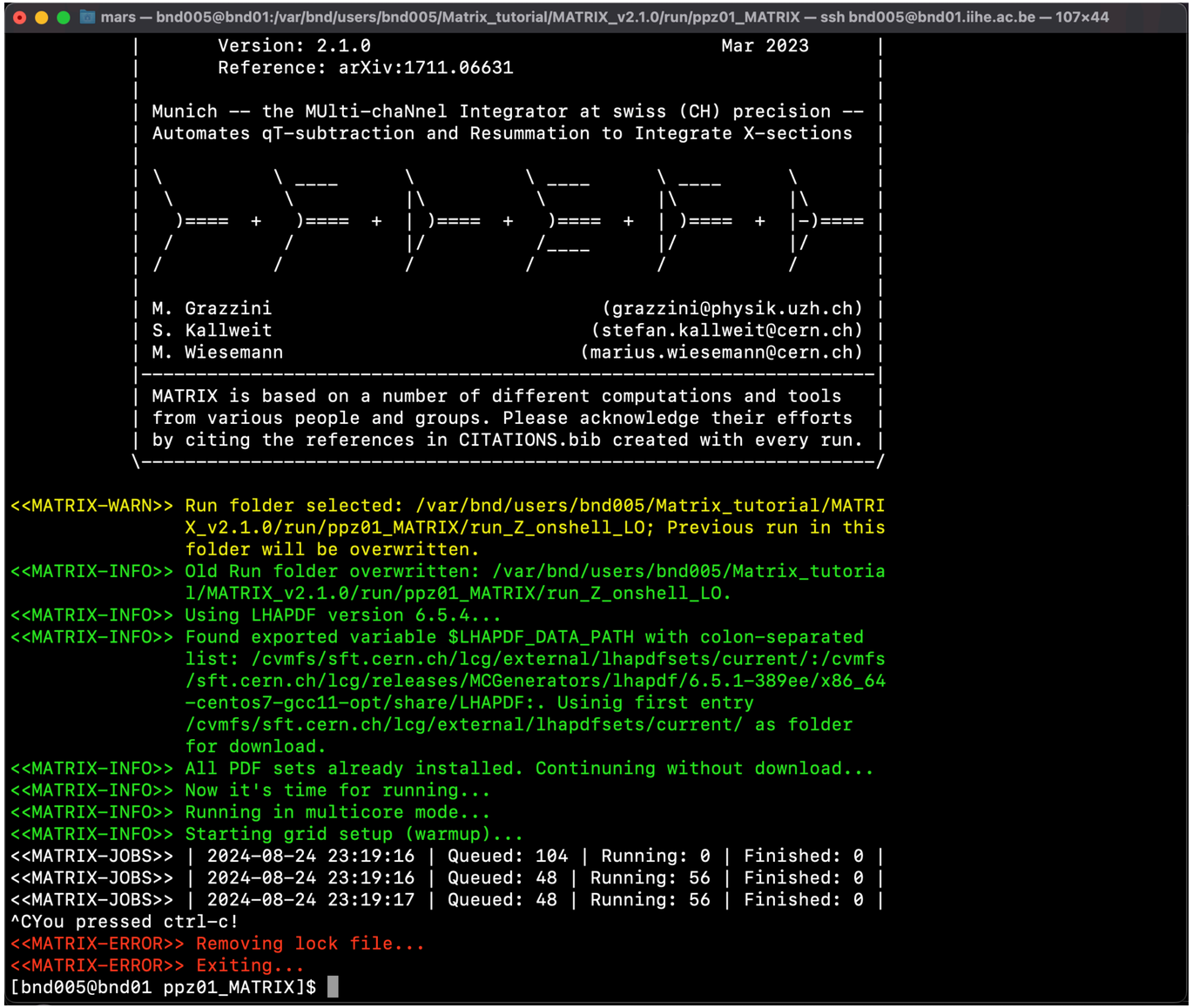


Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NNLO_QCD = 1
> add_NLO_EW = 1
$ ./bin/run_process run_XX
  --run_mode run
```

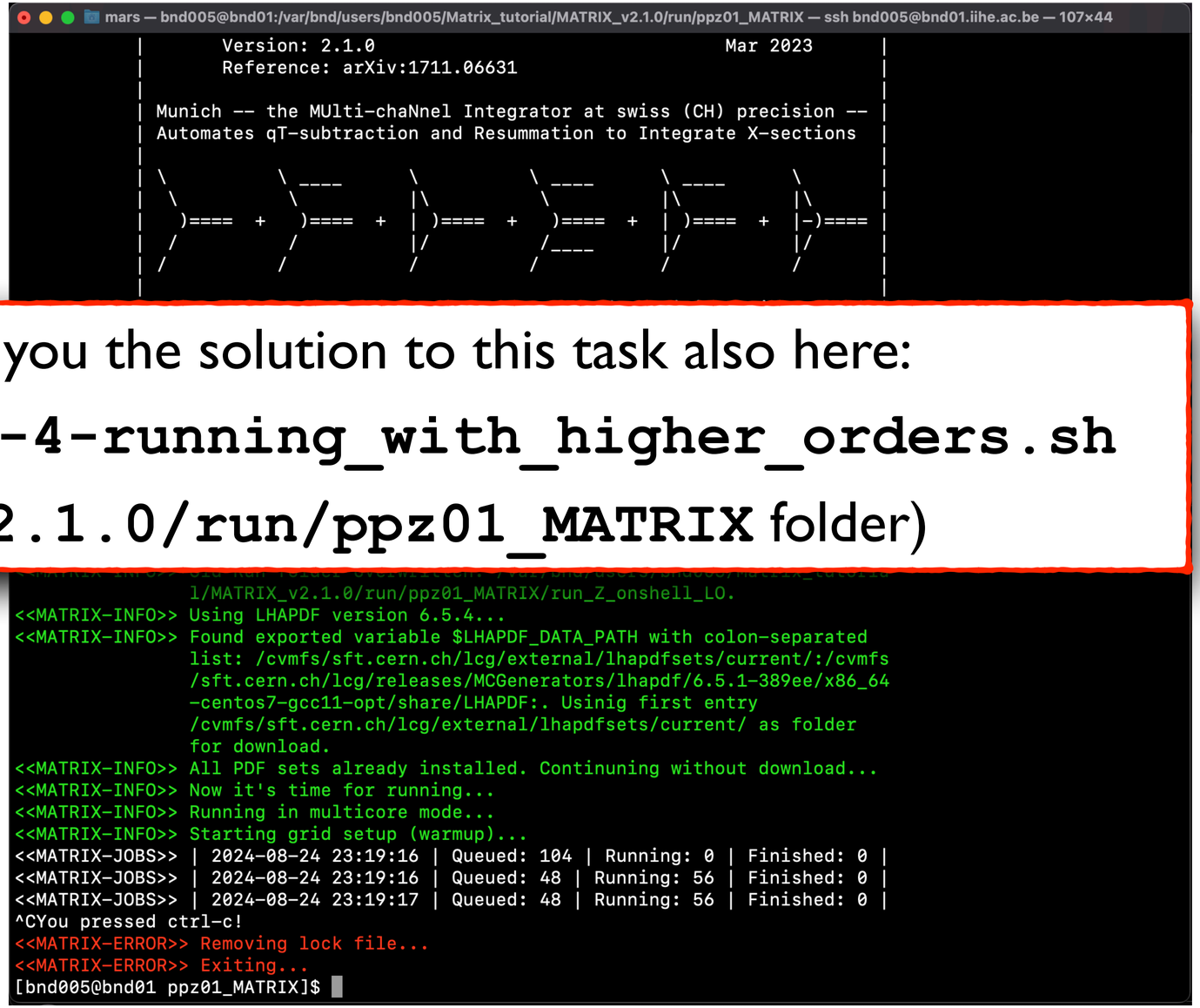
> `ctrl-c` (to stop the code)



Hands on !

- now let's start playing with the inputs…

```
$ emacs -nw input/
run_Z_onshell_LO/parameter.dat
> run_NNLO_QCD = 1
```



If you did not manage to do so, you the solution to this task also here:

`/var/bnd/theo/help/solution-4-running_with_higher_orders.sh`

(execute inside the **`MATRIX_v2.1.0/run/ppz01_MATRIX`** folder)

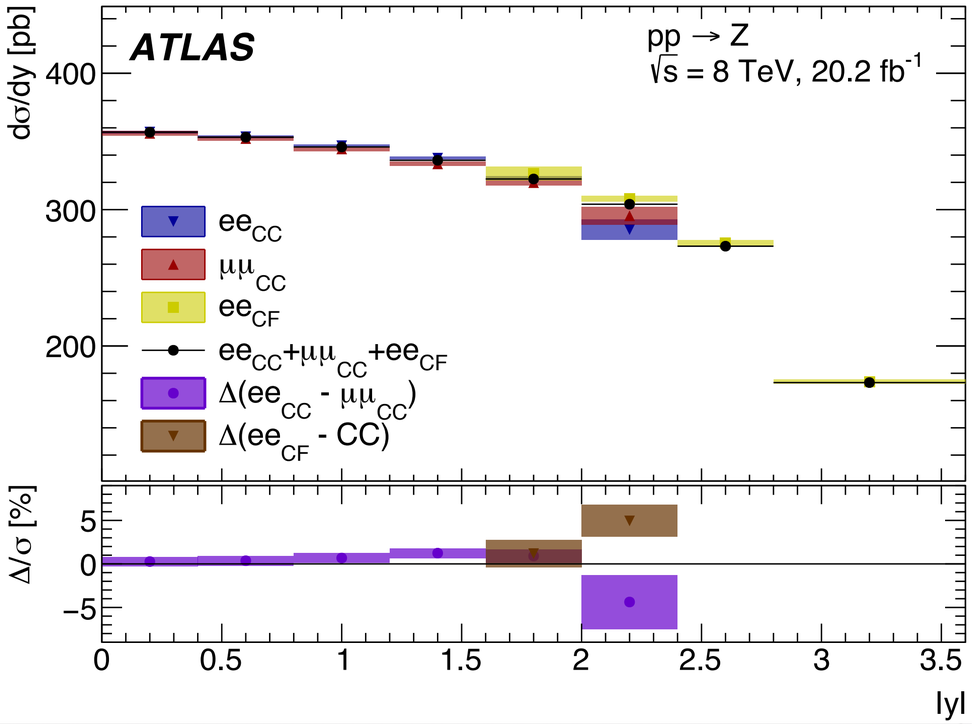
Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data from:

`/var/bnd/theo/matrix/ATLAS_DY_data/y_Z-ATLAS__data.dat`



mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental) ----------

End of buffer

https://www.hepdata.net/record/ins2698794

or download and extract:

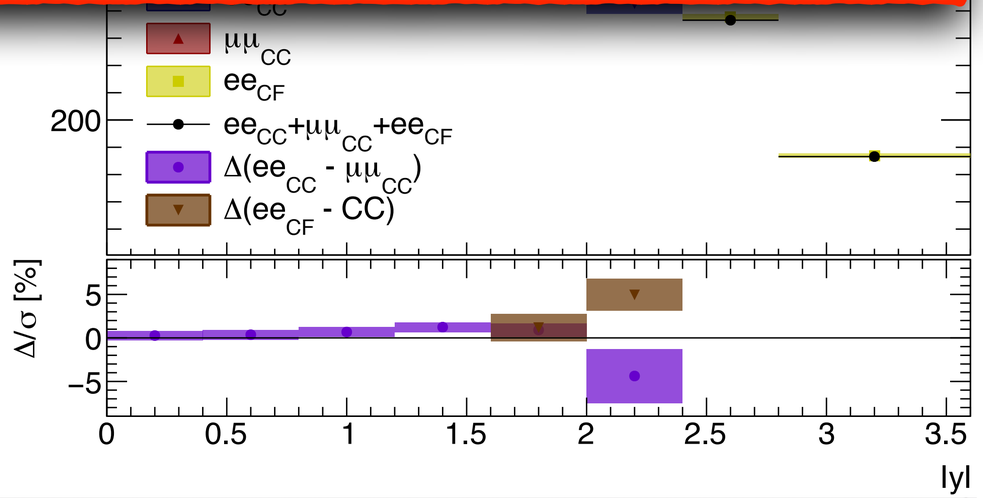
wget https://wwwth.mpp.mpg.de/members/wieseman/download/lectures_and_talks/BND_Summer_School_Lecture/matrix_files.tar

compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data from:

/var/bnd/theo/matrix/ATLAS_DY_data/y_Z-ATLAS__data.dat



mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental) ----------

End of buffer

https://www.hepdata.net/record/ins2698794

Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44

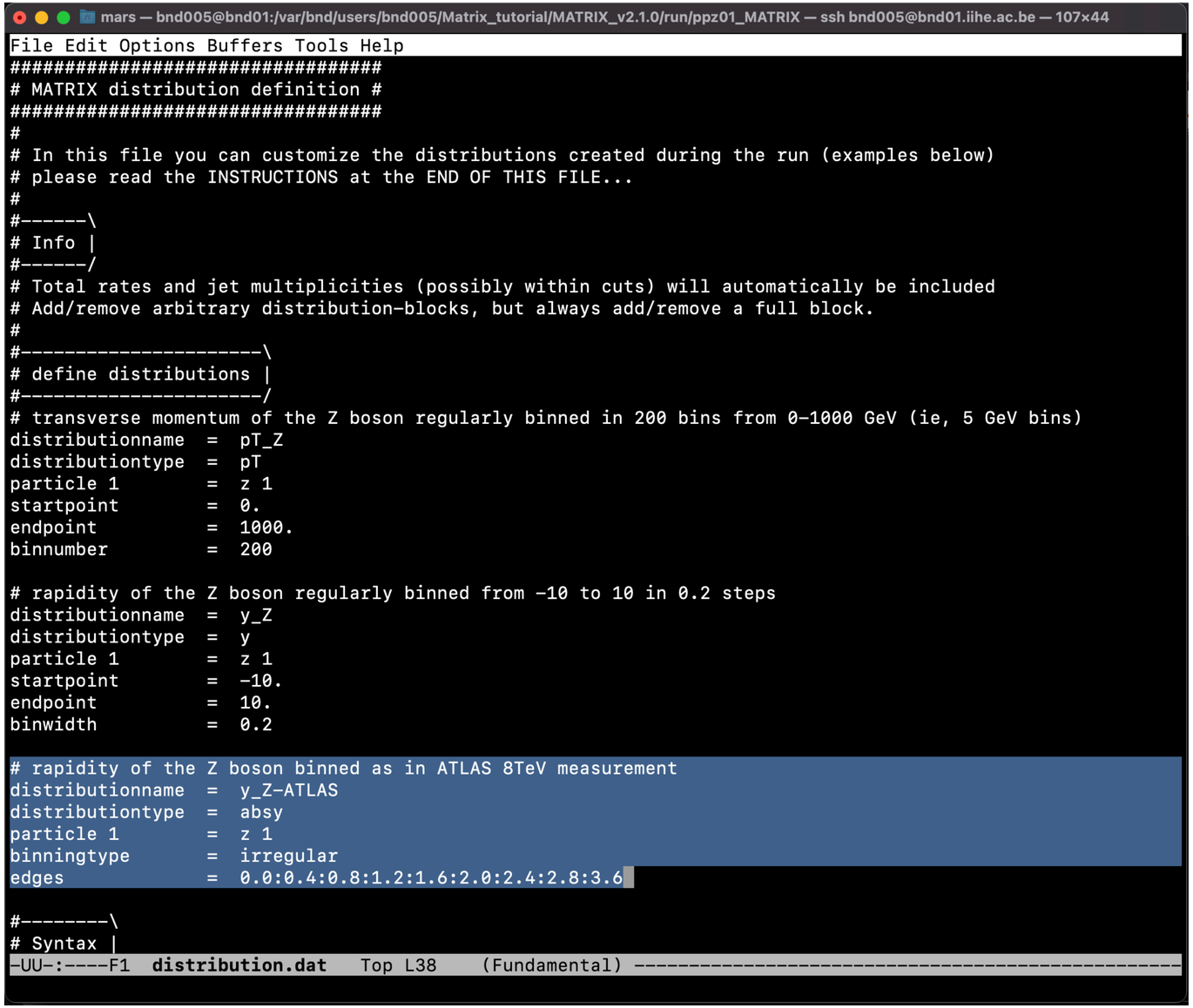
```
File Edit Options Buffers Tools Help
#########################
# MATRIX input parameter #
#########################

#----------------------\
# General run settings |
#----------------------/
process_class    =  pp-z+X       #  process id
E                =  4000.        #  energy per beam
coll_choice      =  1            #  (1) PP collider; (2) PPbar collider
photon_induced   =  1            #  switch to turn on (1) and off (0) photon-induced contributions
enhance_tails    =  0            #  switch to improve statistics in tail of distributions (a factor of two s\
lower)


#-----------------\
# Scale settings |
#-----------------/
scale_ren          =  91.1876    #  renormalization (muR) scale
scale_fact         =  91.1876    #  factorization (muF) scale
dynamic_scale      =  0          #  dynamic ren./fac. scale
                                 #  0: fixed scale above
                                 #  1: invariant mass (Q) of system (of the colourless final states)
                                 #  2: transverse mass (mT^2=Q^2+pT^2) of system (of the colourless final st\
ates)
factor_central_scale = 1.0       #  relative factor for central scale (important for dynamic scales)
scale_variation    =  1          #  switch for muR/muF uncertainties (0) off; (1) 7-point (default); (2) 9-p\
oint variation
variation_factor   =  2          #  symmetric variation factor; usually a factor of 2 up and down (default)


#-----------------------------\
# Order-dependent run settings |
#-----------------------------/
# LO-run
run_LO             =  1          #  switch for LO cross section (1) on; (0) off
LHAPDF_LO          =  NNPDF31_nlo_as_0118_luxqed  #  LO LHAPDF set
PDFsubset_LO       =  0          #  member of LO PDF set
precision_LO       =  1.e-3      #  precision of LO cross section

# NLO-run
-UU-:----F1  parameter.dat    Top L9     (Fundamental) ----------------------------------------------------
```

Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data



Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z-ATLAS__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: y_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: n_jets__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Trying to plot: pT_Z__LO
<<MATRIX-INFO>> Running gnuplot...
<<MATRIX-INFO>> Plot successfully generated.
<<MATRIX-INFO>> Combining all pdf files into single file "all_plots.pdf"...


                  /-------------------------------------------------\
                  |                Final result for:                |
                  |              p p --> Z   @ 8 TeV LHC            |
                  \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                #--------\
                # LO-run |
                #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:2.863e+07 fb +/- 2.7e+04 fb (muR, muF unc.:  +8.3%  -9.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_L
O
```

Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from

If you did not manage to do so, you the solution to this task also here:

`/var/bnd/theo/help/solution-5-comparison_to_ATLAS_data.sh`

(execute inside the **`MATRIX_v2.1.0/run/ppz01_MATRIX`** folder)

following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data

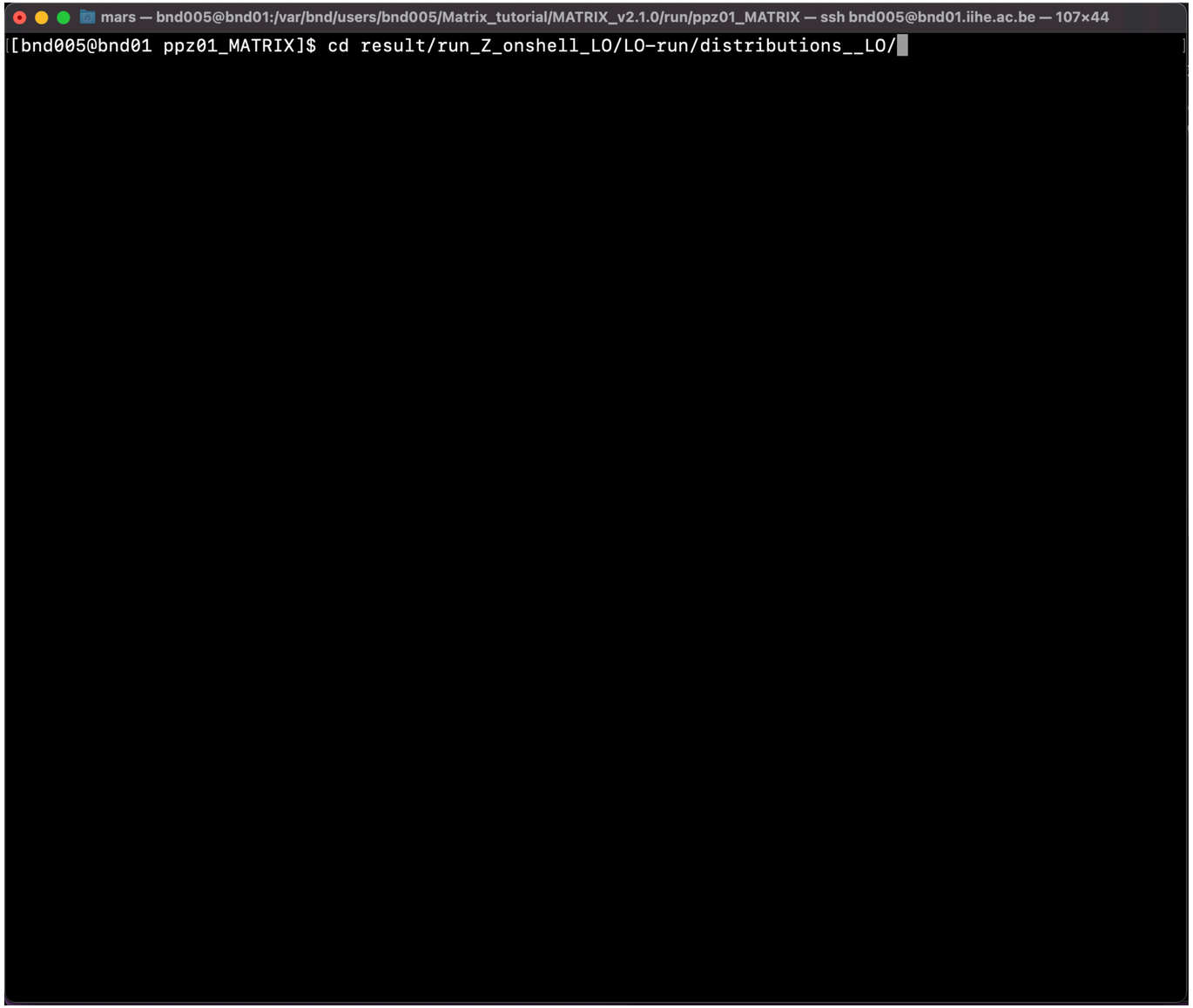
```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX — ssh bnd005@bnd01.iihe.ac.be — 107×44
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 0 | Running: 0 | Finished: 3 |
<<MATRIX-INFO>> All runs successfully finished.
<<MATRIX-INFO>> Cleaning previous results (result run)...
<<MATRIX-INFO>> Collecting and combining results...
<<MATRIX-JOBS>> | 2024-08-25 00:07:26 | Queued: 2 | Running: 0 | Finished: 0 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-JOBS>> | 2024-08-25 00:07:31 | Queued: 0 | Running: 0 | Finished: 2 |
<<MATRIX-INFO>> Plotting results with gnuplot...
<<MATRIX-INFO>> Trying to plot: y_Z-ATLAS__LO
<<MATRIX-INFO>> Running gnuplot...
                    /-------------------------------------------------\
                    |                  Final result for:              |
                    |              p p --> Z   @ 8 TeV LHC            |
                    \-------------------------------------------------/

<MATRIX-RESULT> 1 separate run was made

                  #--------\
                  # LO-run |
                  #--------/
<MATRIX-RESULT> PDF: NNPDF31_nlo_as_0118_luxqed
<MATRIX-RESULT> Total rate (possibly within cuts):
<MATRIX-RESULT> ------------------------------------------------------------
<MATRIX-RESULT> LO:2.863e+07 fb +/- 2.7e+04 fb (muR, muF unc.:  +8.3%  -9.5%)
<MATRIX-RESULT> ------------------------------------------------------------

<MATRIX-RESULT> All results (including the distributions) can be found in:
<MATRIX-RESULT> /var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_L
O
```

Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data



Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

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3. perform LO run
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Hands on !

- let's do something more useful and compare to actual LHC data!

task: consider recent inclusive measurement at 8 TeV from ATLAS of Z rapidity (y) and transverse momentum (p_T) distribution and calculate LO result with MATRIX with the following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data

Hands on !

- let's do something more useful and compare to actual LHC data!

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...

```
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
1.6	2	8554068.6	37922.6	7716082.1	34401.6	9290072.7	40996.2	-9.80%	8.60%
2	2.4	7999456.6	26386.3	7268964.1	24008.3	8634291.1	28458.0	-9.13%	7.94%
2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental) ----------

End of buffer

following steps:

1. change energy to 8 TeV
2. implement y distribution
3. perform LO run
4. compare to data

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
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2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

ATLAS data

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
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2	2.4	7999456.6	26386.3	7268964.1	24008.3	8634291.1	28458.0	-9.13%	7.94%
2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

MATRIX with the following

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

ATLAS data

first bin ($0 \leq |y_Z| \leq 0.4$):

LO: $\sigma_{\text{LO}}(pp \to Z) = 9568545\,\text{fb}$

data: $\sigma_{\text{ATLAS}}(pp \to \ell^+\ell^-) = 357.152\,\text{pb}$

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
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2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

MATRIX with the following

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
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2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

ATLAS data

first bin ($0 \leq |y_Z| \leq 0.4$):

LO: $\sigma_{\text{LO}}(pp \to Z) = 9568.54\,\text{pb}$

data: $\sigma_{\text{ATLAS}}(pp \to \ell^+\ell^-) = 357.152\,\text{pb}$

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
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2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

MATRIX with the following

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

$$\mathrm{BR}(Z \to \ell^+\ell^-) \simeq 3.36\,\%$$

ATLAS data

first bin ($0 \le |y_Z| \le 0.4$):

LO: $\sigma_{\mathrm{LO}}(pp \to Z) = 9568.54\,\mathrm{pb}$

data: $\sigma_{\mathrm{ATLAS}}(pp \to \ell^+\ell^-) = 357.152\,\mathrm{pb}$

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
1.6	2	8554068.6	37922.6	7716082.1	34401.6	9290072.7	40996.2	-9.80%	8.60%
2	2.4	7999456.6	26386.3	7268964.1	24008.3	8634291.1	28458.0	-9.13%	7.94%
2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

$$\mathrm{BR}(Z \to \ell^+\ell^-) \simeq 3.36\,\%$$

ATLAS data

first bin ($0 \le |y_Z| \le 0.4$):

LO: $\sigma_{\mathrm{LO}}(pp \to Z \to \ell^+\ell^-) = 321.503\,\mathrm{pb}$

data: $\sigma_{\mathrm{ATLAS}}(pp \to \ell^+\ell^-) = 357.152\,\mathrm{pb}$

Hands on !

- let's do something more useful and compare to actual LHC data!

```
mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO —...
[bnd005@bnd01 ppz01_MATRIX]$ cd result/run_Z_onshell_LO/LO-run/distributions__LO/
[bnd005@bnd01 distributions__LO]$ ls
n_jets__LO.dat  pT_Z__LO.dat  total_rate__LO.dat  y_Z-ATLAS__LO.dat  y_Z__LO.dat
[bnd005@bnd01 distributions__LO]$ emacs -nw y_Z-ATLAS__LO.dat
```

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz01_MATRIX/result/run_Z_onshell_LO/LO-run/distributions__LO — ssh bnd005@bnd01.iihe.ac.be — 149×13

File Edit Options Buffers Tools Help

# left-edge	right-edge	scale-central	central-error	scale-min	min-error	scale-max	max-error	rel-down	rel-up
0	0.4	9568545.5	29160.3	8498220.1	25956.8	10522877.	32059.6	-11.19%	9.97%
0.4	0.8	9457907.5	29396.6	8415650.7	26334.7	10385636.	32118.3	-11.02%	9.81%
0.8	1.2	9269091.2	30938.0	8274944.5	27831.1	10151223.	33680.1	-10.73%	9.52%
1.2	1.6	8909453.2	40351.2	7990765.3	36501.2	9721126.6	43722.1	-10.31%	9.11%
1.6	2	8554068.6	37922.6	7716082.1	34401.6	9290072.7	40996.2	-9.80%	8.60%
2	2.4	7999456.6	26386.3	7268964.1	24008.3	8634291.1	28458.0	-9.13%	7.94%
2.4	2.8	7186338.0	31852.7	6591525.4	29136.3	7693900.5	34193.4	-8.28%	7.06%
2.8	3.6	4605174.2	10158.4	4305013.1	9435.54	4847905.5	10757.6	-6.52%	5.27%

-UU-:----F1 **y_Z-ATLAS__LO.dat** All L10 (Fundamental)

End of buffer

MATRIX with the following

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/ppz0...

File Edit Options Buffers Tools Help

# left-edge	right-edge	exp-cross-section	total-error	lumi-error
0	0.4	357.152	0.610232	6.52312
0.4	0.8	353.152	0.612877	6.35674
0.8	1.2	345.985	0.614565	6.22773
1.2	1.6	336.195	0.631117	6.05151
1.6	2	322.483	0.867255	5.80469
2	2.4	303.973	1.222500	5.47151
2.4	2.8	273.198	1.477950	4.91756
2.8	3.6	173.171	1.448840	3.11708

-UU-:----F1 **y_Z-ATLAS__data.dat** All L10 (Fundamental)

End of buffer

$$\mathrm{BR}(Z \to \ell^+\ell^-) \simeq 3.36\,\%$$

ATLAS data

first bin ($0 \le |y_Z| \le 0.4$):

LO: $\sigma_{\mathrm{LO}}(pp \to Z \to \ell^+\ell^-) = 321\,\mathrm{pb}$

data: $\sigma_{\mathrm{ATLAS}}(pp \to \ell^+\ell^-) = 357\,\mathrm{pb}$

+11 %

NNLO Comparison to LHC data

task: Check out the prepared NNLO run inside
`/var/bnd/theo/matrix/ppz01_MATRIX`
Does the NNLO QCD on-shell Z rapidity distribution compare well with data? And if not, why can you imagine why not?
Check instead the prepared off-shell Z production NNLO run inside
`/var/bnd/theo/matrix/ppeex02_MATRIX`
Does it compare better or worse to data? What is the main difference?

hint: Compare the input files of the two runs to find the difference.

(reminder, the data is here: **`/var/bnd/theo/matrix/ATLAS_DY_data`**)

or download and extract:

`wget https://wwwth.mpp.mpg.de/members/wieseman/download/lectures_and_talks/BND_Summer_School_Lecture/matrix_files.tar`

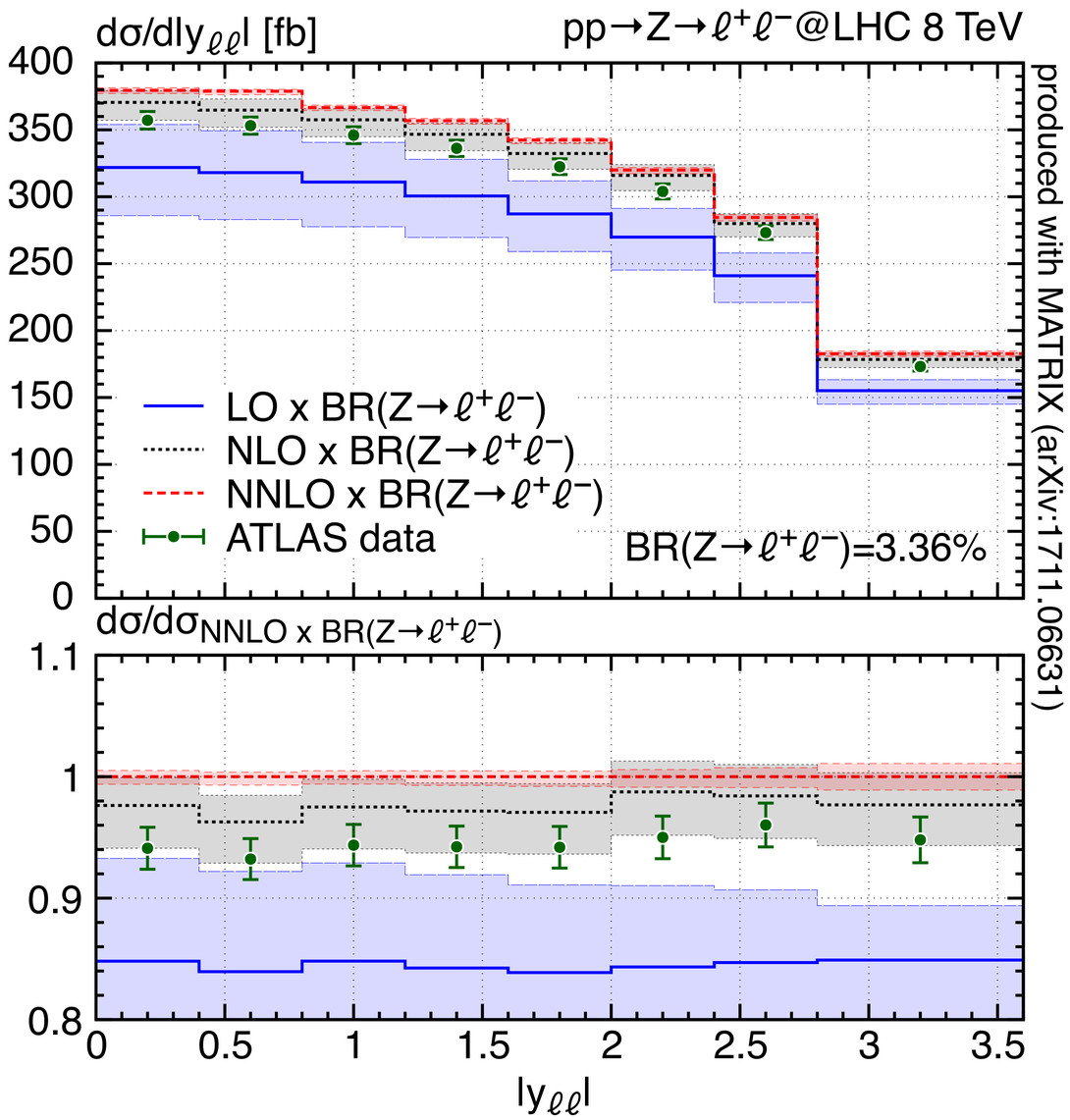
NNLO Comparison to LHC data

task: Check out the prepared NNLO run inside
`/var/bnd/theo/matrix/ppz01_MATRIX`
Does the NNLO QCD on-shell Z rapidity distribution compare well with data? And if not, why can you imagine why not?
Check instead the prepared off-shell Z production NNLO run inside
`/var/bnd/theo/matrix/ppeex02_MATRIX`
Does it compare better or worse to data? What is the main difference?

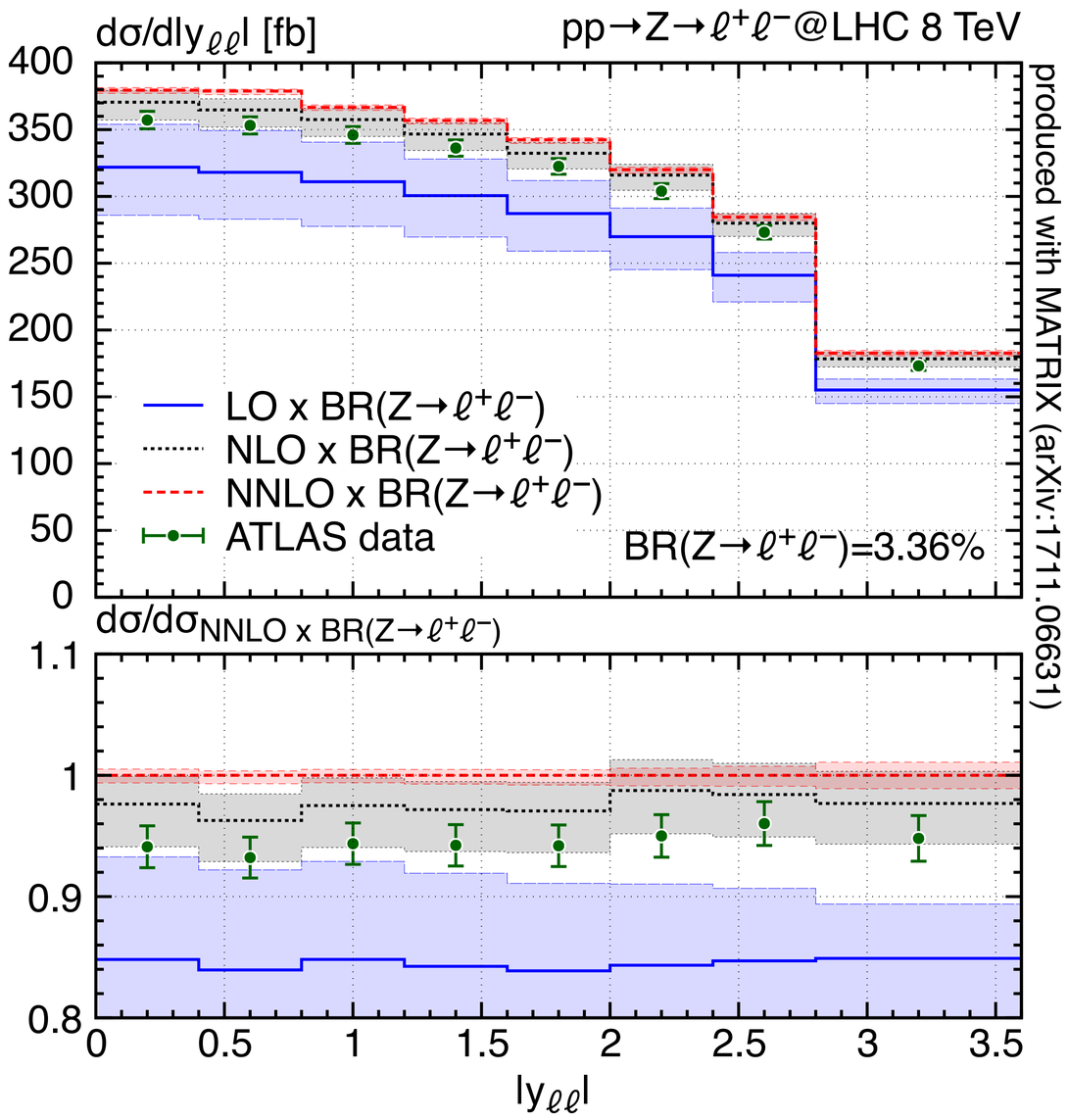
hint: Compare the input files of the two runs to find the difference.

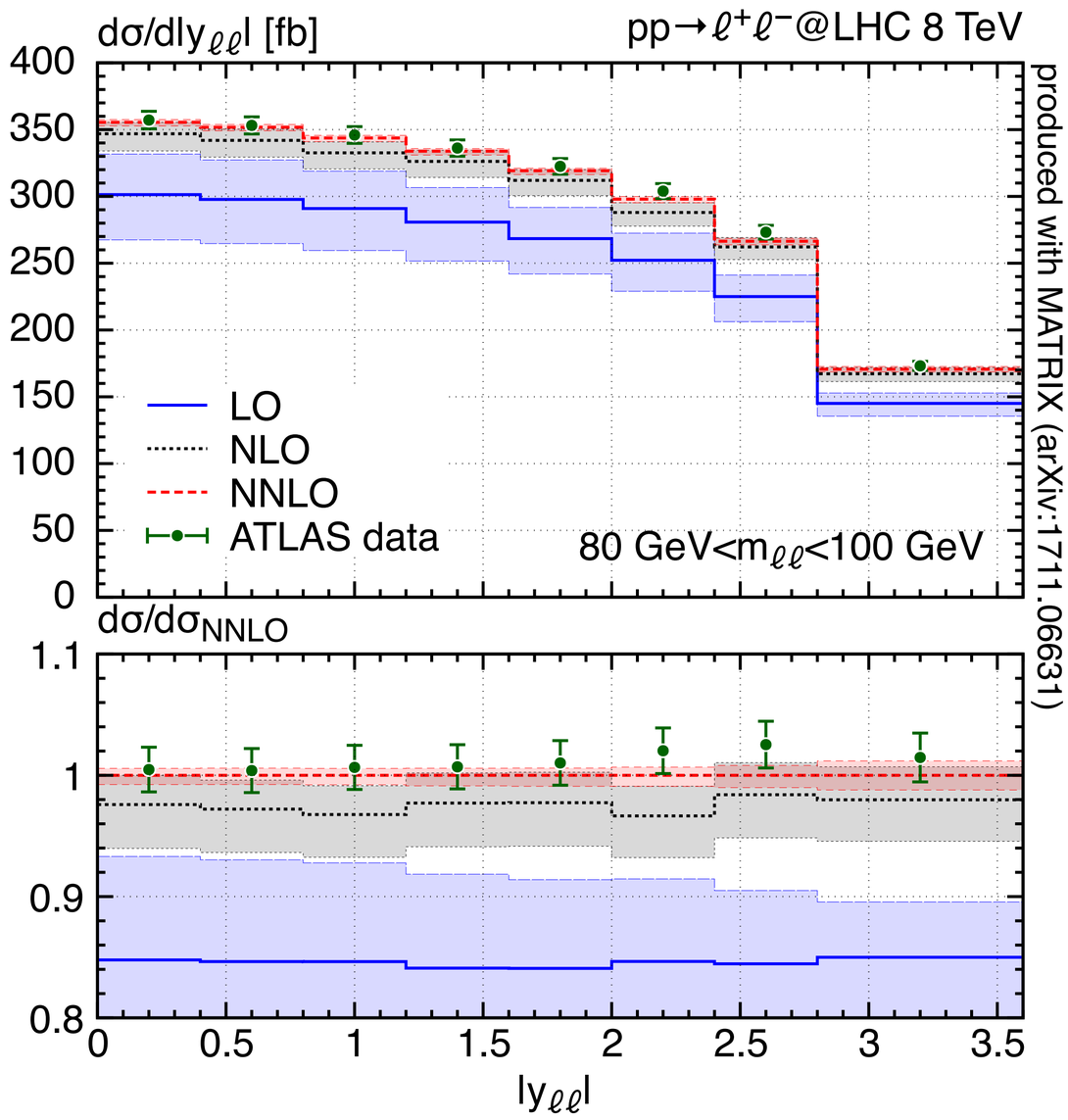
answer: The on-shell Z (times BR) rapidity distribution at NNLO is ~5% above the data. The NNLO off-shell result agrees within a few permille with the data. The reason is the $80 \leq m_{\ell^+\ell^-} \leq 100$ mass window cut, which removes ~5% of the cross section. The on-shell process is inclusive over the lepton momenta (by construction), missing this effect.

NNLO Comparison to LHC data

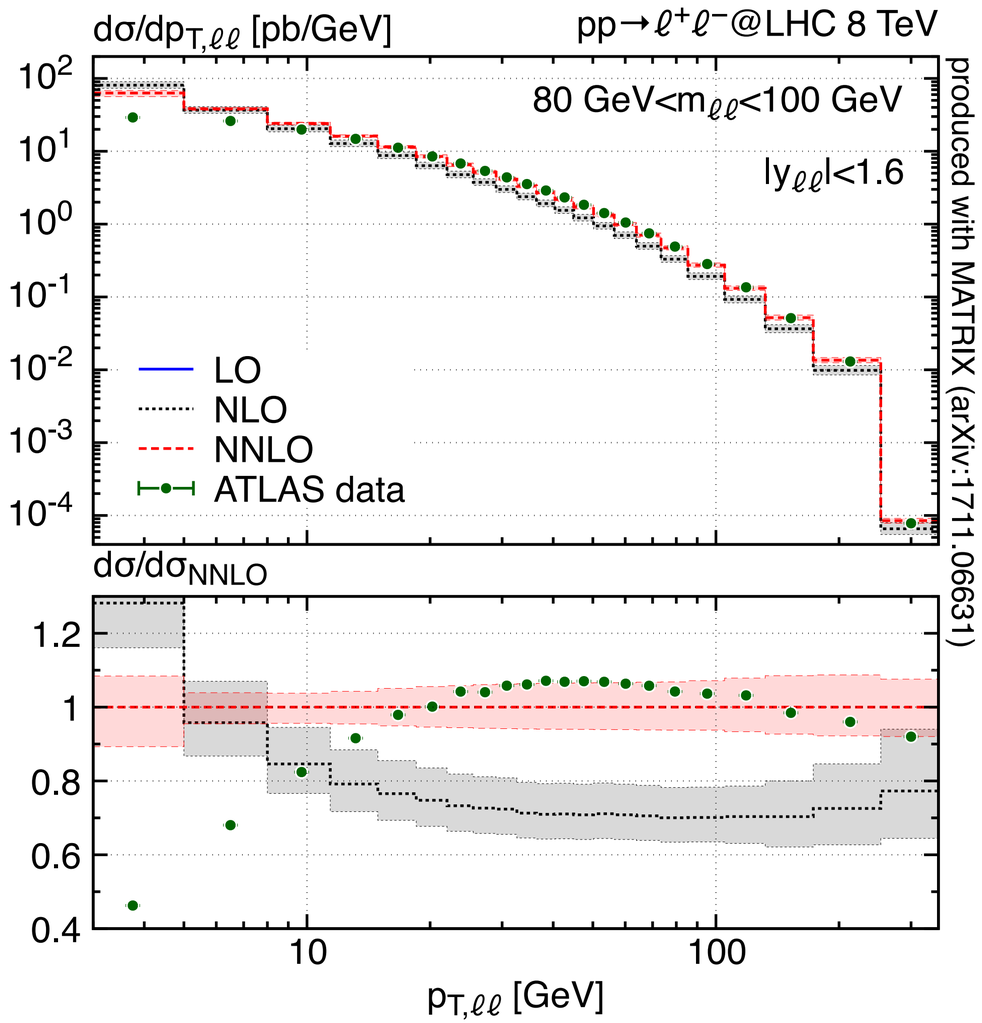


NNLO Comparison to LHC data

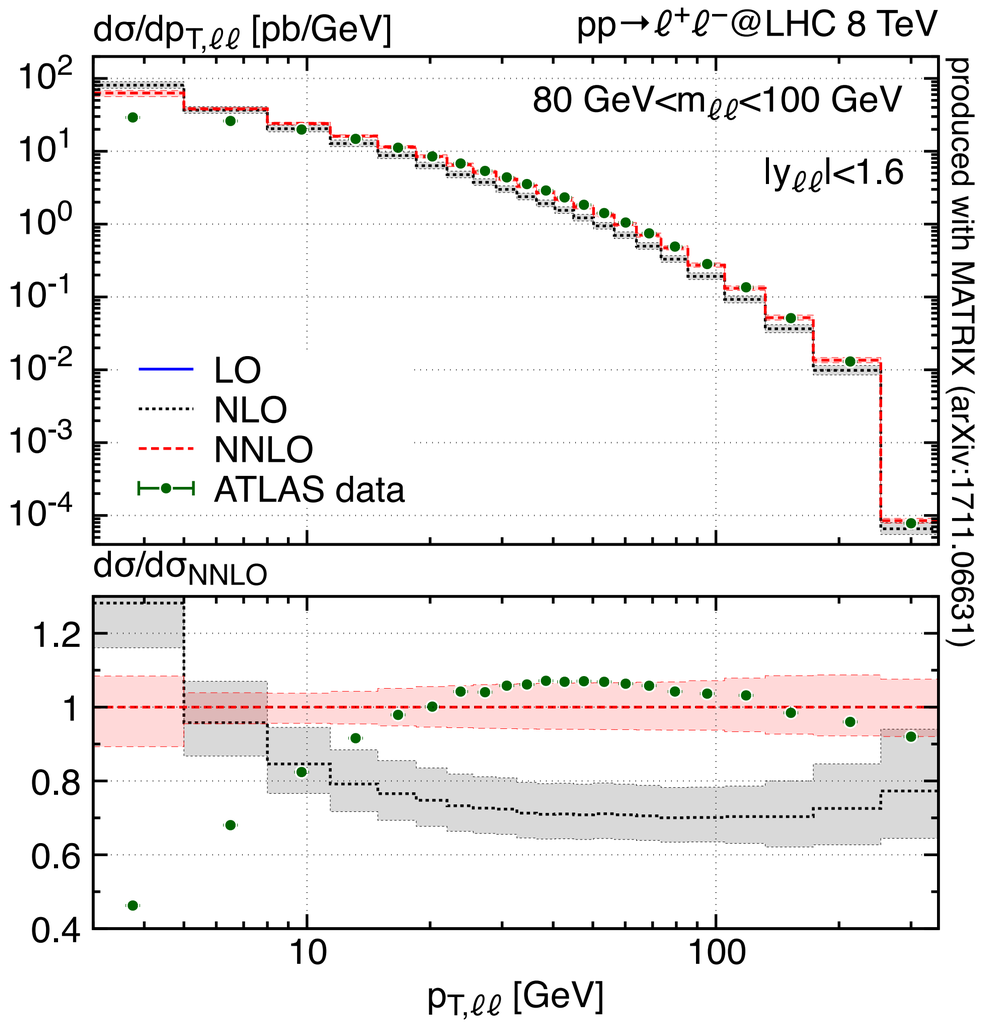


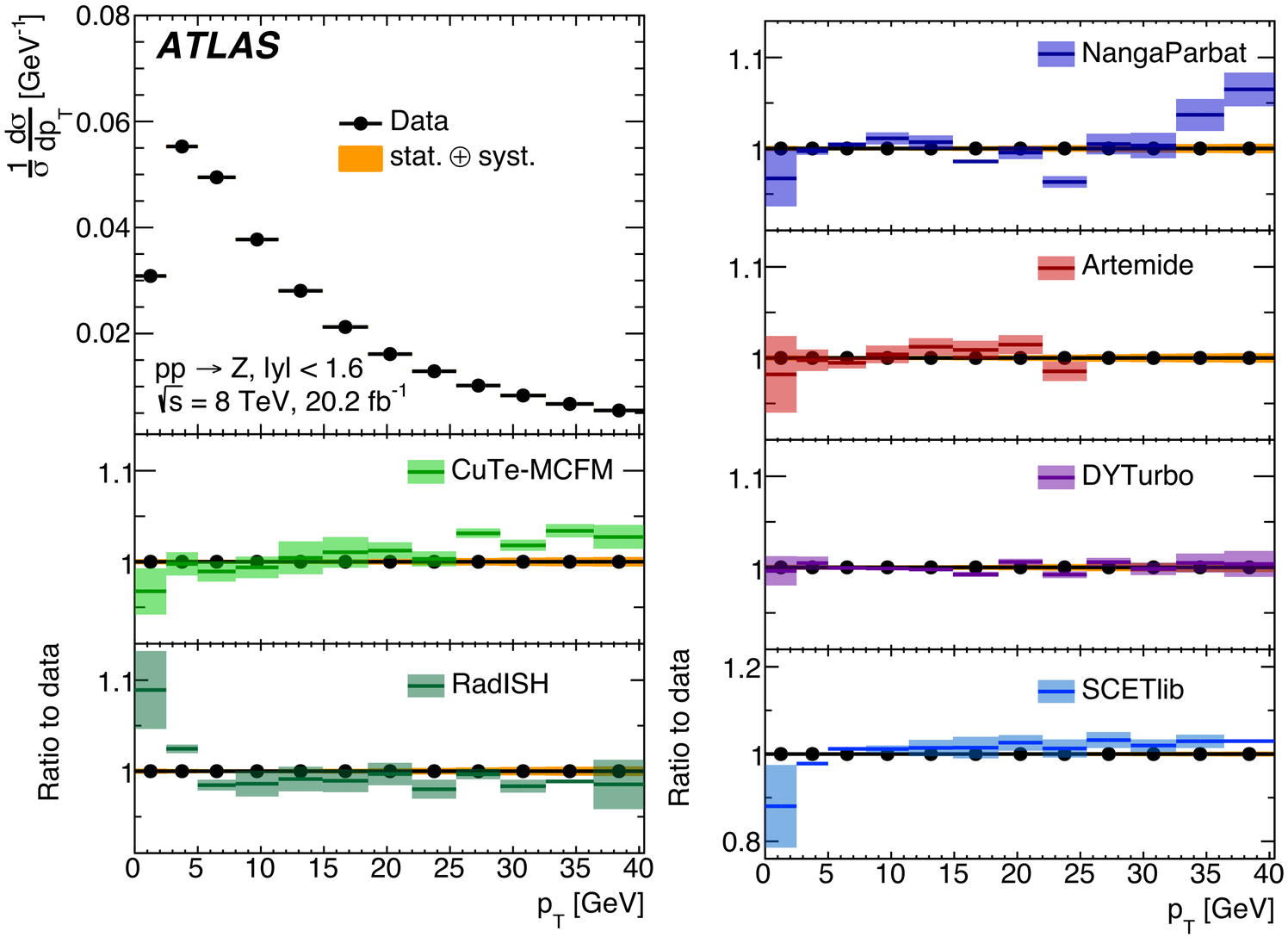


NNLO Comparison to LHC data



NNLO Comparison to LHC data





Diphoton Production

task: Compile diphoton production. Look at the input files of diphoton and Drell-Yan production. Do you notice any important difference?

hint: It has to do with the photons in the final state for diphoton production.

tip: Instead of compiling (which may take some time) you can compare the input files directly inside here (process shortcut you need to figure out): **`run/input_files/${process}/default.input.MATRIX/`**

Diphoton Production

task: Compile diphoton production. Look at the input files of diphoton and Drell-Yan production. Do you notice any important difference?

hint: It has to do with the photons in the final state for diphoton production.

mars — bnd005@bnd01:/var/bnd/users/bnd005/Matrix_tutorial/MATRIX_v2.1.0/run/input_files/ppaa02/default.input.MATRIX — ssh bnd005@bnd01.iihe.a...

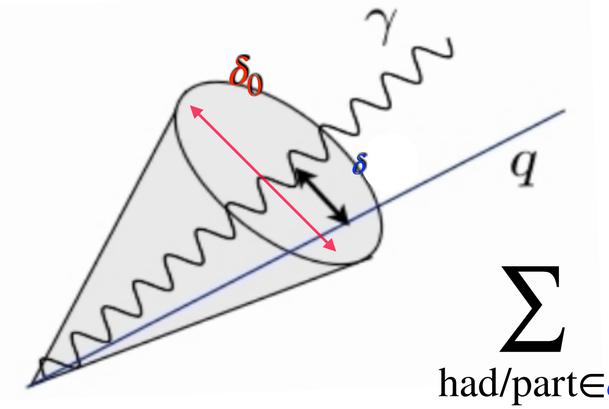
```
File Edit Options Buffers Tools Help
#----------------------------\
# Settings for fiducial cuts |
#----------------------------/
# Jet algorithm
jet_algorithm = 3               #  (1) Cambridge-Aachen (2) kT (3) anti-kT
jet_R_definition = 0            #  (0) pseudo-rapidity (1) rapidity
jet_R = 0.4                     #  DeltaR

# Frixione isolation
frixione_isolation = 1          #  switch for Frixione isolation (0) off;
                                #  (1) with frixione_epsilon, used by ATLAS;
                                #  (2) with frixione_fixed_ET_max, used by CMS
frixione_n = 1                  #  exponent of delta-term
frixione_delta_0 = 0.4          #  maximal cone size
frixione_epsilon = 0.5          #  photon momentum fraction
#frixione_fixed_ET_max = 5.      #  fixed maximal pT inside cone

-UU-:----F1  parameter.dat    49% L85     (Fundamental) ----------------------------------------------------
```

Diphoton Production

task: Compile diphoton production. Look at the input files of diphoton and Drell-Yan production. Do you notice any important difference?

hint: It has to do with the photons in the final state for diphoton production.

answer: Photons in the final state need to be isolated in an infrared-safe way. Otherwise, you need to include non-perturbative fragmentation functions, which most calculations/codes (including MATRIX) do not provide. An infared-safe approach that completely kills the fragmentation component is Frixione's smooth-cone isolation.



Isolate photon ("throw away" all hadron/partons) when for given cone (radius δ_0) around photon, for every cone $\delta < \delta_0$ the entire hadronic/partonic transverse energy inside is smaller than a reference energy scale that smoothly decreases with δ.

$$\sum_{\text{had/part}\in\delta} E_T^{\text{had/part}} \leq E_T^{\text{max}}(\delta) = E_T^{\text{ref}} \cdot \left(\frac{1-\cos|\,\delta}{1-\cos\delta_0}\right)^n, \quad \forall\delta \leq \delta_0, \quad E_T^{\text{ref}} = \epsilon_\gamma p_T^\gamma \text{ or } E_T^{\text{ref}} = p_T^0$$

Diphoton Production

task: Look at prepared NNLO runs in folders for diphoton and Drell-Yan production (see below). Look at the dependence of the cross section on the q_T-subtraction cutoff r_{cut} of the two processes. What do you notice? What causes this behaviour?

hint: It has to do with what we just discussed.

tip: Instead of looking at/plotting the whole r_{cut} dependence, look at NNLO cross section in the summary of the two processes. Do you notice a difference in the results between the two processes at a fixed r_{cut} compared to the $r_{\text{cut}} \to 0$ extrapolation? What happens to the numerical/systematical error?

Drell-Yan: `/var/bnd/theo/matrix/ppz01_MATRIX/run_matrix_tutorial_8TeV_on-shell_Z_ATLAS/result/result..MATRIX.NNLO.result/fixed-scale/complete/band.qTcut.NNLO.QCD__NNLORUN.dat`

diphoton: `/var/bnd/theo/matrix/ppaa02_MATRIX/run_matrix_tutoral_diphoton/result/result..MATRIX.NNLO.result/dynamic-scale-1/7-point/band.qTcut.NNLO.QCD__NNLORUN.dat`

Diphoton Production

Drell-Yan

#qTcut	central scale xiR=1 xiF=1	
0	33958573.	14976.349
0.15	33967335.	9840.7316
0.16	33967139.	9637.6593
0.17	33970123.	9357.7266
0.18	33964391.	9277.9947
0.19	33967671.	9656.8093
0.2	33969563.	8968.4672
...	...	...
0.95	33973627.	8482.9472
0.96	33964844.	5304.3165
0.97	33967026.	5327.2331
0.98	33966695.	5269.2587
0.99	33962589.	5355.0294
1	33964258.	5215.9660

lders for diphoton and Drell-Yan
e dependence of the cross section on the
o processes. What do you notice? What

ussed.

hole r_{cut} dependence, look at NNLO cross
processes. Do you notice a difference in
sses at a fixed r_{cut} compared to the
ens to the numerical/systematical error?

n_matrix_tutorial_8TeV_on-shell_Z_ATLAS/result/
le/complete/band.qTcut.NNLO.QCD__NNLORUN.dat

diphoton: `/var/bnd/theo/matrix/ppaa02_MATRIX/run_matrix_tutoral_diphoton/result/result..MATRIX.NNLO.result/dynamic-scale-1/7-point/band.qTcut.NNLO.QCD__NNLORUN.dat`

Diphoton Production

Drell-Yan

#qTcut	central scale xiR=1 xiF=1	
0	33958573.	14976.349
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0.2	33969563.	8968.4672
...	...	
0.95	33973627.	8482.9472
0.96	33964844.	5304.3165
0.97	33967026.	5327.2331
0.98	33966695.	5269.2587
0.99	33962589.	5355.0294
1	33964258.	5215.9660

extremely stable, variation at sub-permille level

0.01 % ...

lders for diphoton and Drell-Yan
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processes. Do you notice a difference in
sses at a fixed r_{cut} compared to the
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n_matrix_tutorial_8TeV_on-shell_Z_ATLAS/result/
le/complete/band.qTcut.NNLO.QCD__NNLORUN.dat

diphoton: /var/bnd/theo/matrix/ppaa02_MATRIX/run_matrix_tutoral_diphoton/result/
result..MATRIX.NNLO.result/dynamic-scale-1/7-point/band.qTcut.NNLO.QCD__NNLORUN.dat

Diphoton Production

Drell-Yan

#qTcut	central scale xiR=1 xiF=1	
0	33958573.	14976.349
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0.18	33964391.	9277.9947
0.19	33967671.	9656.8093
0.2	33969563.	8968.4672
…	…	…
0.95	33973627.	8482.9472
0.96	33964844.	5304.3165
0.97	33967026.	5327.2331
0.98	33966695.	5269.2587
0.99	33962589.	5355.0294
1	33964258.	5215.9660

extremely stable; variation at sub-permille level

0.01 %

diphoton

#	central scale mu_R = 1.0	-- mu_F = 1.0
0	37663.925	205.89370
0.15	38068.859	31.094659
0.16	38094.585	30.507834
0.17	38120.731	30.256576
0.18	38152.198	29.833181
0.19	38169.268	29.459856
0.2	38198.945	30.062169
…	…	…
0.95	39307.604	24.180129
0.96	39317.268	24.168141
0.97	39320.553	24.176465
0.98	39334.327	24.139060
0.99	39338.161	24.126061
1	39347.663	24.140364

diphoton: `/var/bnd/theo/matrix/ppaa02_MATRIX/run_matrix_tutoral_diphoton/result/result..MATRIX.NNLO.result/dynamic-scale-1/7-point/band.qTcut.NNLO.QCD__NNLORUN.dat`

Diphoton Production

Drell-Yan

```
#qTcut          central scale
#               xiR=1  xiF=1
0               33958573.       14976.349
0.15            33967335.       9840.7316
0.16            33967139.       9637.6593
0.17            33970123.       9357.7266
0.18            33964391.       9277.9947
0.19            33967671.       9656.8093
0.2             33969563.       8968.4672
 ...                ...
0.95            33973627.       8482.9472
0.96            33964844.       5304.3165
0.97            33967026.       5327.2331
0.98            33966695.       5269.2587
0.99            33962589.       5355.0294
1               33964258.       5215.9660
```

extremely stable; variation at sub-permille level

0.01 % ...

diphoton

```
#               central scale
#               mu_R = 1.0  --  mu_F = 1.0
0               37663.925       205.89370
0.15            38068.859       31.094659
0.16            38094.585       30.507834
0.17            38120.731       30.256576
0.18            38152.198       29.833181
0.19            38169.268       29.459856
0.2             38198.945       30.062169
 ...                ...
0.95            39307.604       24.180129
0.96            39317.268       24.168141
0.97            39320.553       24.176465
0.98            39334.327       24.139060
0.99            39338.161       24.126061
1               39347.663       24.140364
```

large r_{cut} dependence; variation at percent level

3.4 % ...

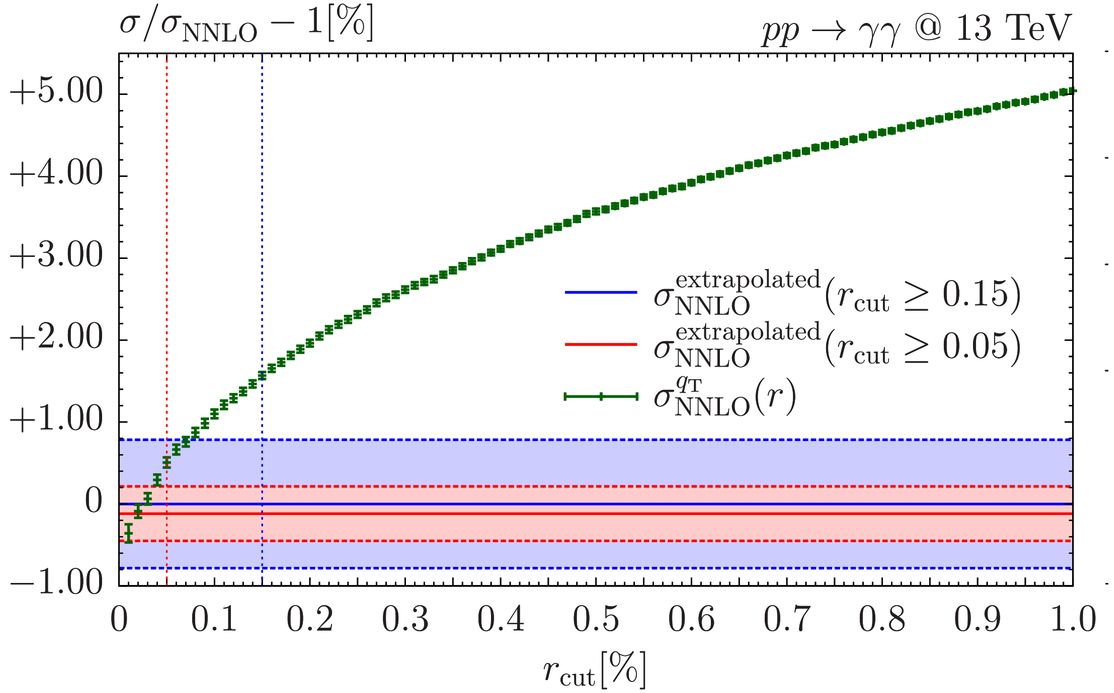
diphoton: `/var/bnd/theo/matrix/ppaa02_MATRIX/run_matrix_tutoral_diphoton/result/result..MATRIX.NNLO.result/dynamic-scale-1/7-point/band.qTcut.NNLO.QCD__NNLORUN.dat`

Diphoton Production

task: Look at prepared NNLO runs in folders for diphoton and Drell-Yan production (see below). Look at the dependence of the cross section on the q_T-subtraction cutoff r_{cut} of the two processes. What do you notice? What causes this behaviour?

hint: It has to do with what we just discussed.

answer: Photon isolation causes the power corrections to turn linear instead of the usual quadratic behaviour. This substantially worsens the r_{cut} convergence and induces larger systematic uncertainties (see large num./syst. error of diphoton cross section).



Go and run the code on some cluster!

- **`MATRIX_v1.0.0/config/Matrix_configuration`**
  handles configuration, like: **`mode`** to choose local/cluster running,
  `cluster_name` to choose cluster (LSF, slurm, ...)
  (soft link in each **`${process_id}_MATRIX/input/Matrix_configuration`**)

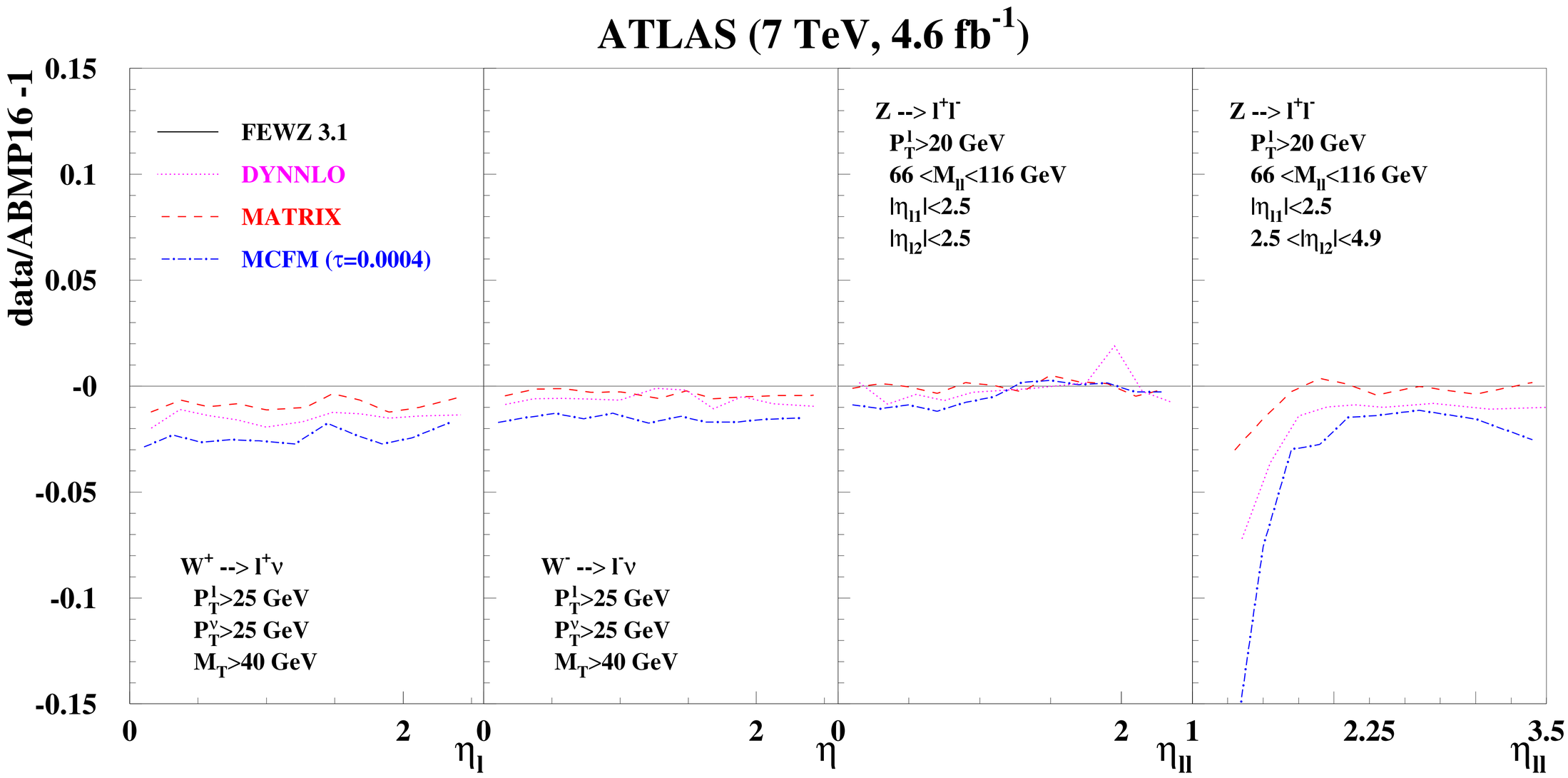
```
############################
# MATRIX configuration file #
############################
# This file contains all parameters to configure MATRIX
# In the run_folders this is the link to the central configuration file
# in MATRIX/config/; you can replace the link by a copy to have individual
# configurations for the different processes

# Editor to be used to edit input files from MATRIX shell
# (default: use the one specified under environmental variable EDITOR)
#default_editor = emacs  # eg, emacs, vi, nano, ...

# runmode of MATRIX: 0 -- multicore (default)
#                    1 -- cluster
mode = 0

######################
## cluster parameter ##
######################
# Name of cluster currently supported:
#   slurm, LSF (eg, lxplus), condor, qsub (Torque/OpenPBS tested+working; PBS, SGE not tested)
cluster_name = LSF

# Queue/Partition of cluster to be used for running
cluster_queue = 2nw

# Maximal runtime for a single process on a single node,
# too low values may lead failure of the code
#cluster_runtime = 2-00:00:00

# add customizable lines at the beginning of cluster submission file
# this allows to add certain cluster-specific requirements as options to the submission
# eg: cluster_submit_line1 = #SBATCH --mem-per-cpu=4000
#     to increase the memory of a slurm job on certain clusters
#cluster_submit_line1 =
#cluster_submit_line2 =
#cluster_submit_line3 =
```


FREE YOUR MIND
THE MATRIX

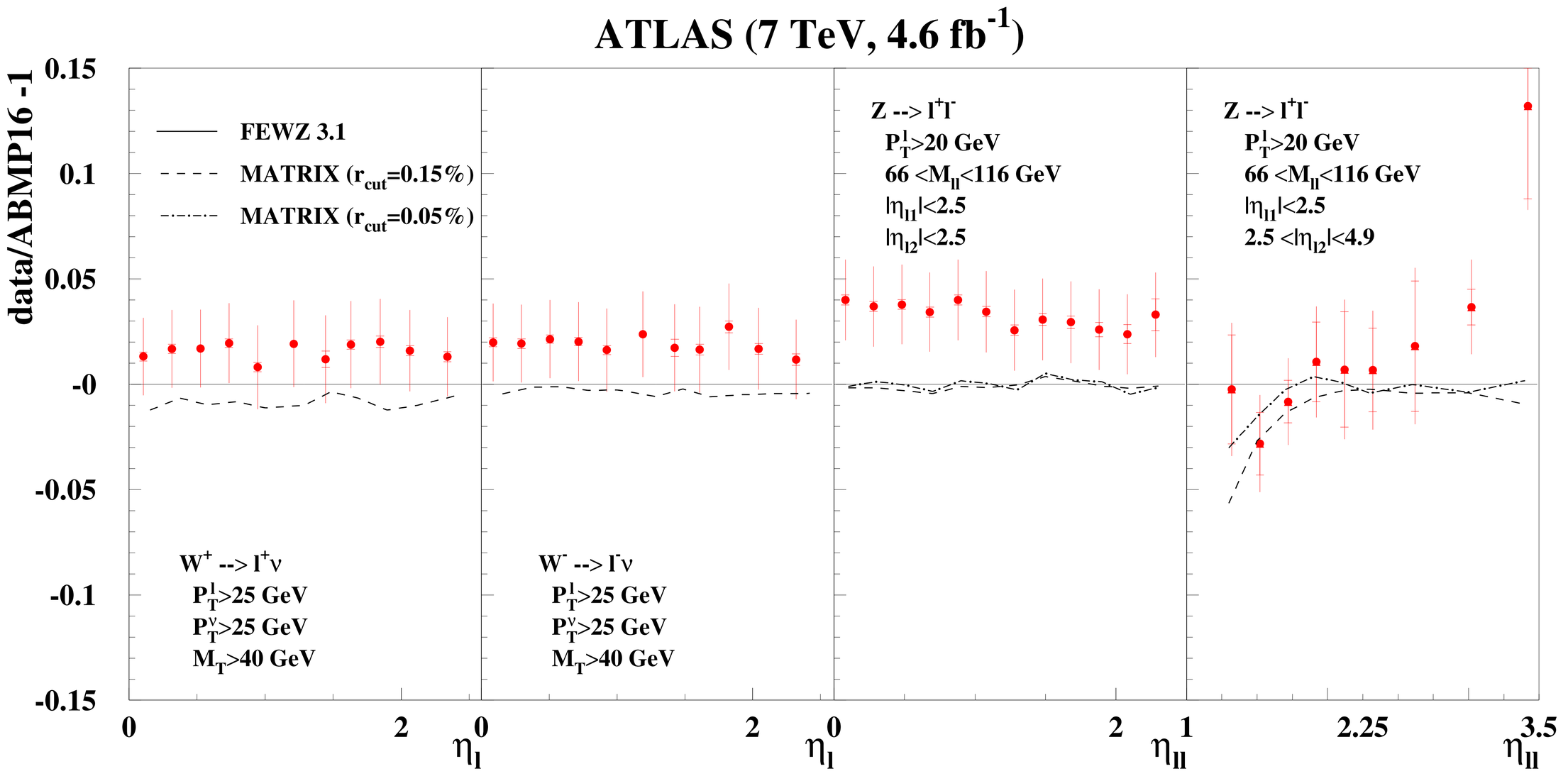
Thank You !

Back Up

[Alekhin, Kardos, Moch, Trócsányi '21]

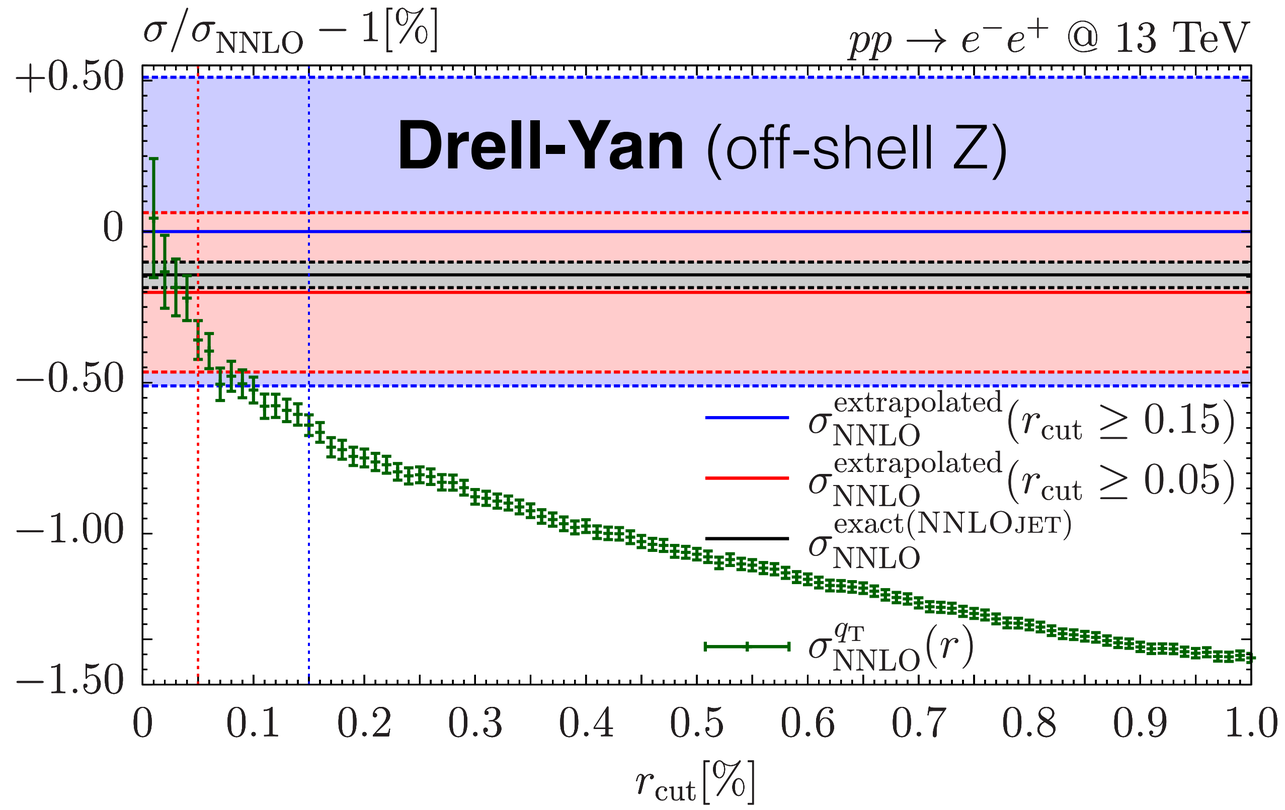


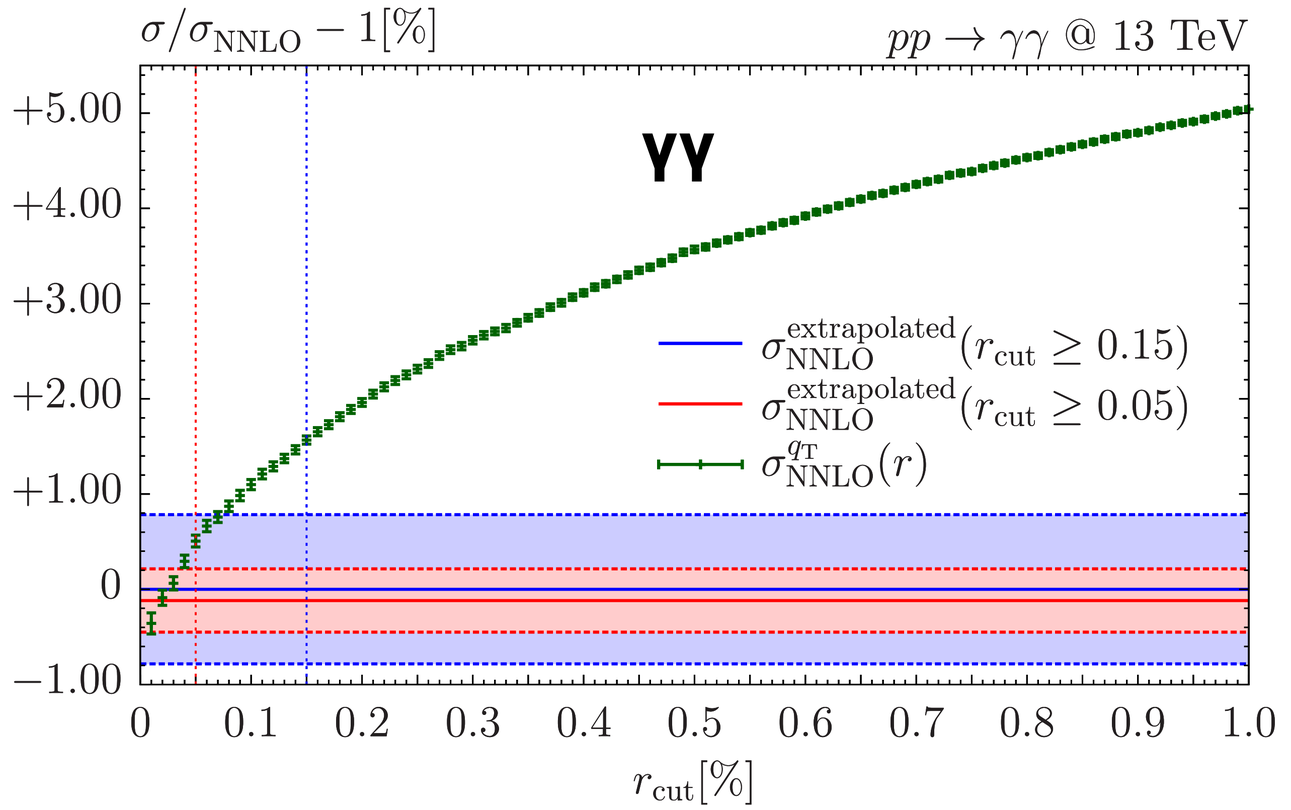
[Alekhin, Kardos, Moch, Trócsányi '21]



$r_{cut} \to 0$ extrapolation in MATRIX

[Grazzini, Kallweit, MW '17]



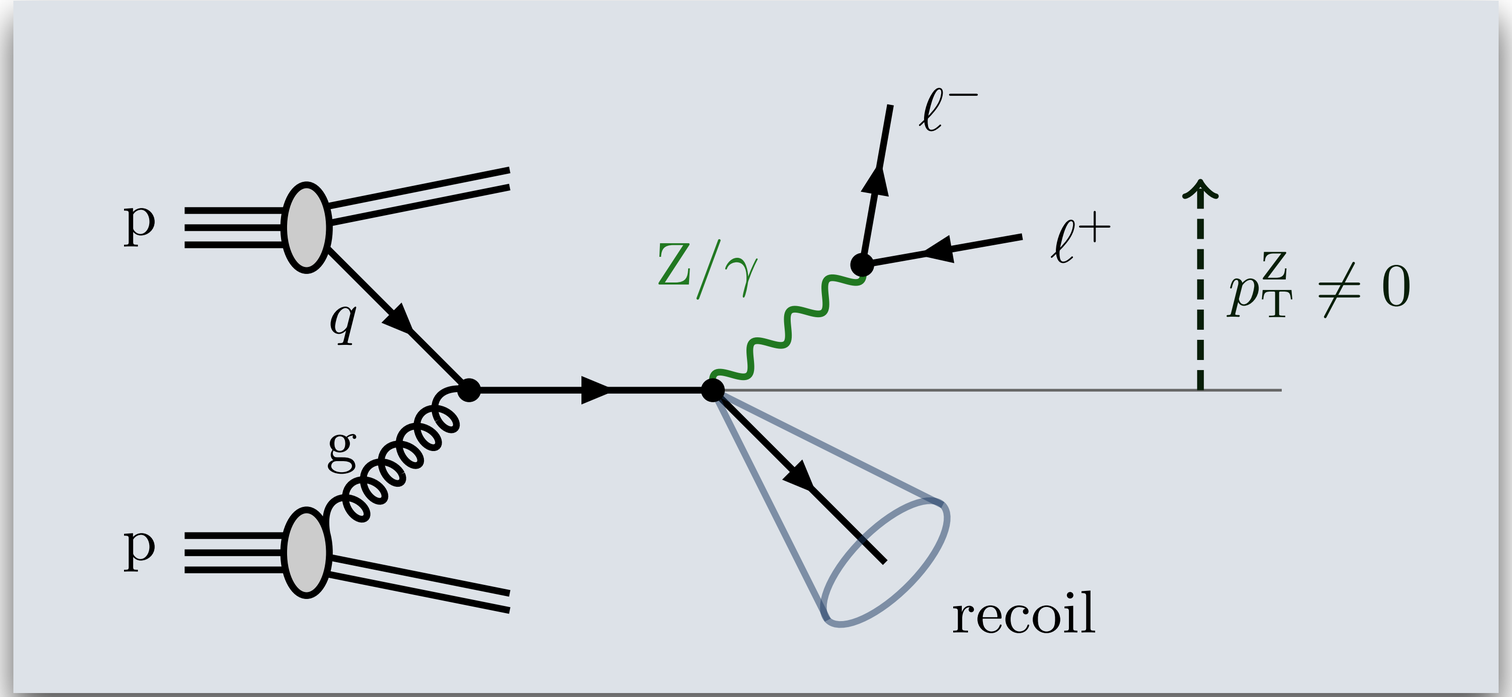


[Gehrmann, Gehrmann-De Ridder, Glover, Huss et al.]

[Buonocore, Kallweit, Rottolli, MW '21]

$$\Delta\sigma^{\text{linPCs}}(r_{\text{cut}}) = \int d\Phi_F \int_{\epsilon}^{r_{\text{cut}}} dr' \left(\frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F^{\text{rec}}) - \frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F) \right),$$

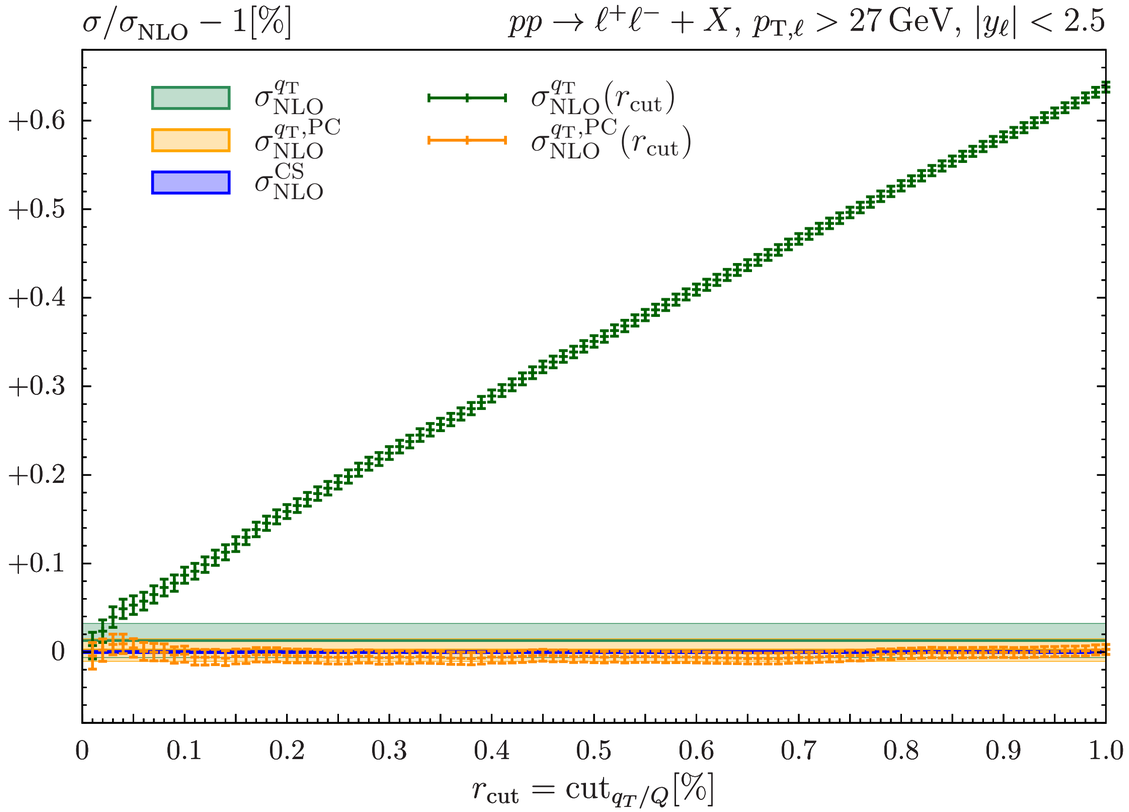
based on observation: linPCs described by recoil [Ebert, Michel, Stewart, Tackmann '21]



[Buonocore, Kallweit, Rottolli, MW '21]

$$\Delta\sigma^{\text{linPCs}}(r_{\text{cut}}) = \int d\Phi_F \int_{\epsilon}^{r_{\text{cut}}} dr' \left(\frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F^{\text{rec}}) - \frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F) \right),$$

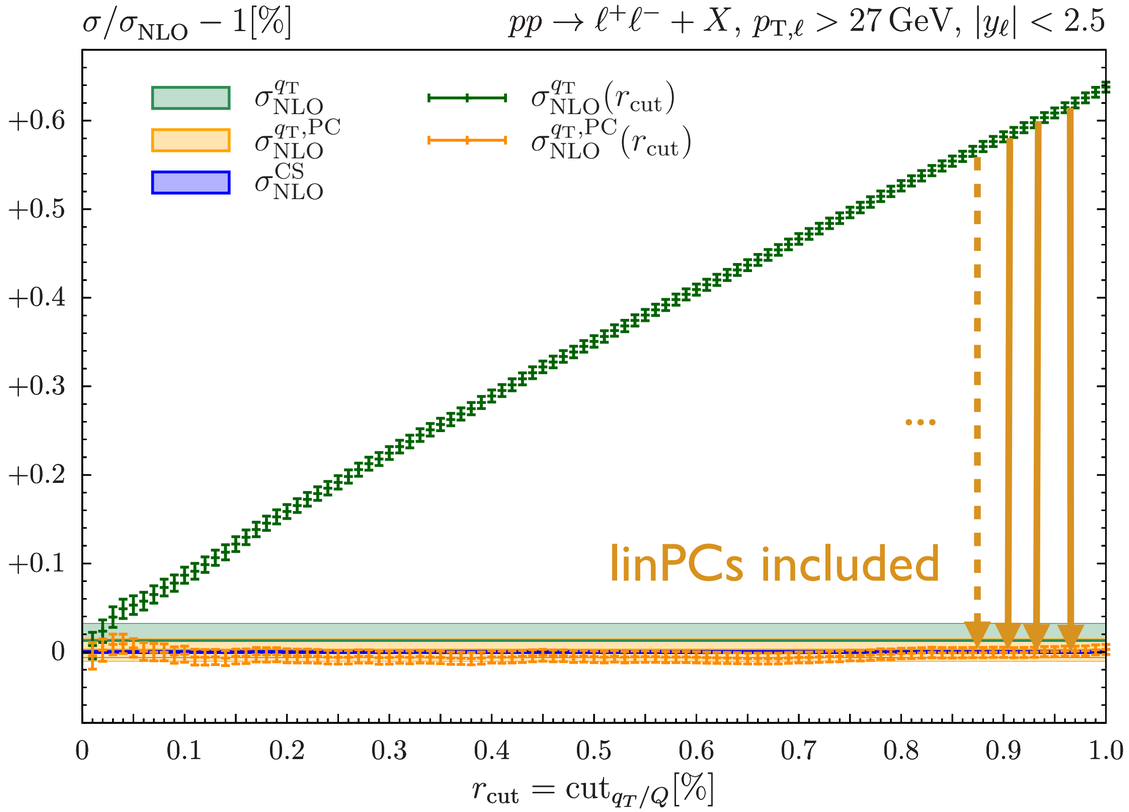
based on observation: linPCs described by recoil [Ebert, Michel, Stewart, Tackmann '21]



[Buonocore, Kallweit, Rottolli, MW '21]

$$\Delta\sigma^{\text{linPCs}}(r_{\text{cut}}) = \int d\Phi_F \int_{\epsilon}^{r_{\text{cut}}} dr' \left(\frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F^{\text{rec}}) - \frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F) \right),$$

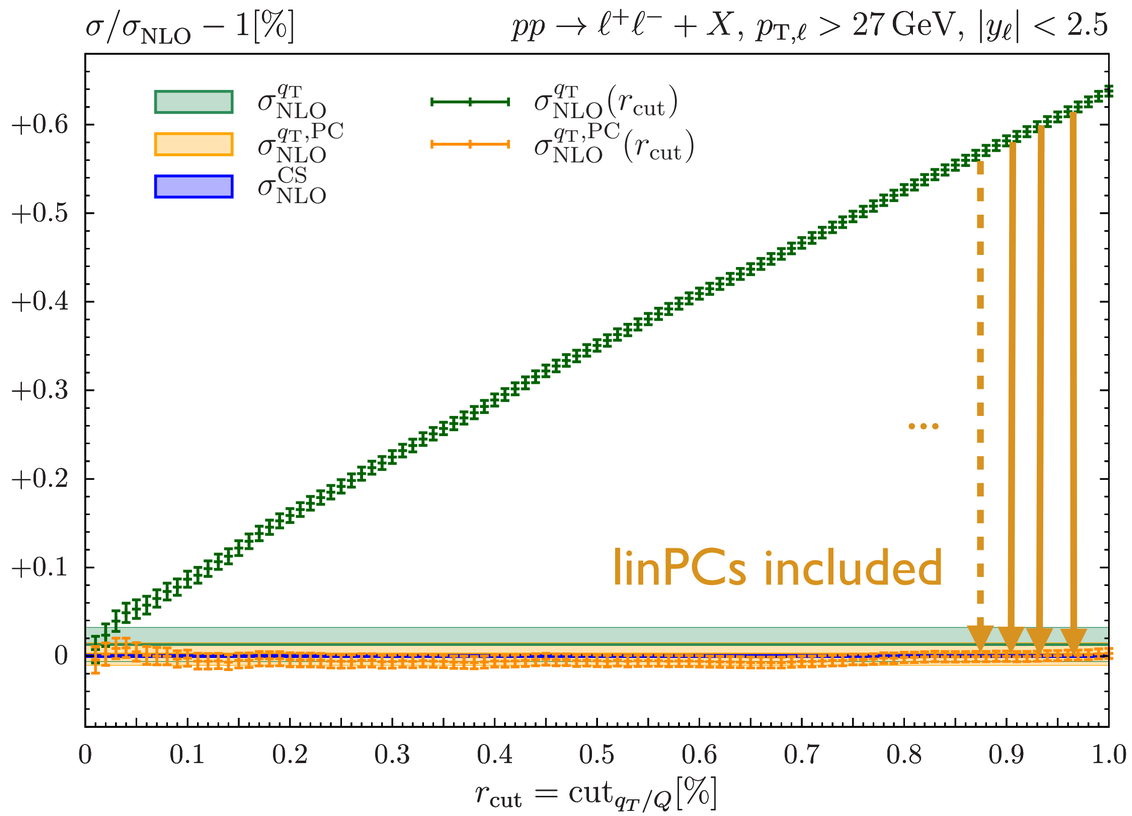
based on observation: linPCs described by recoil [Ebert, Michel, Stewart, Tackmann '21]

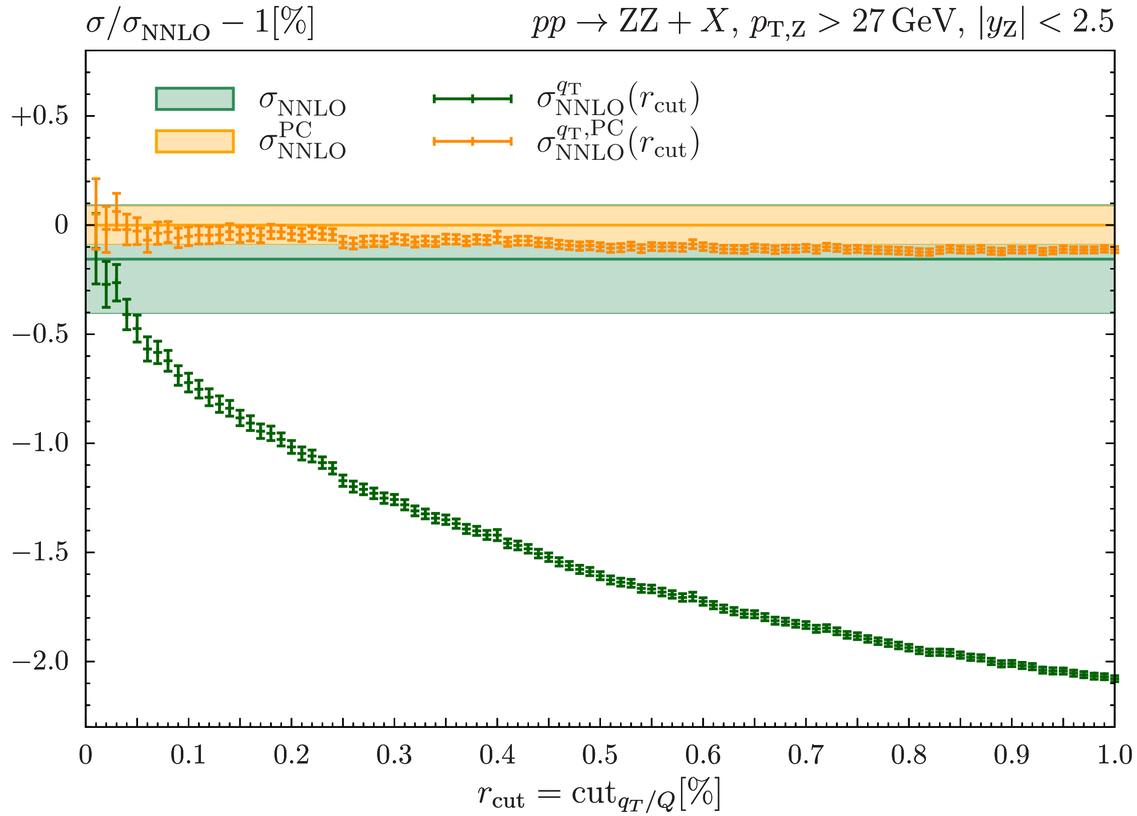


[Buonocore, Kallweit, Rottolli, MW '21]

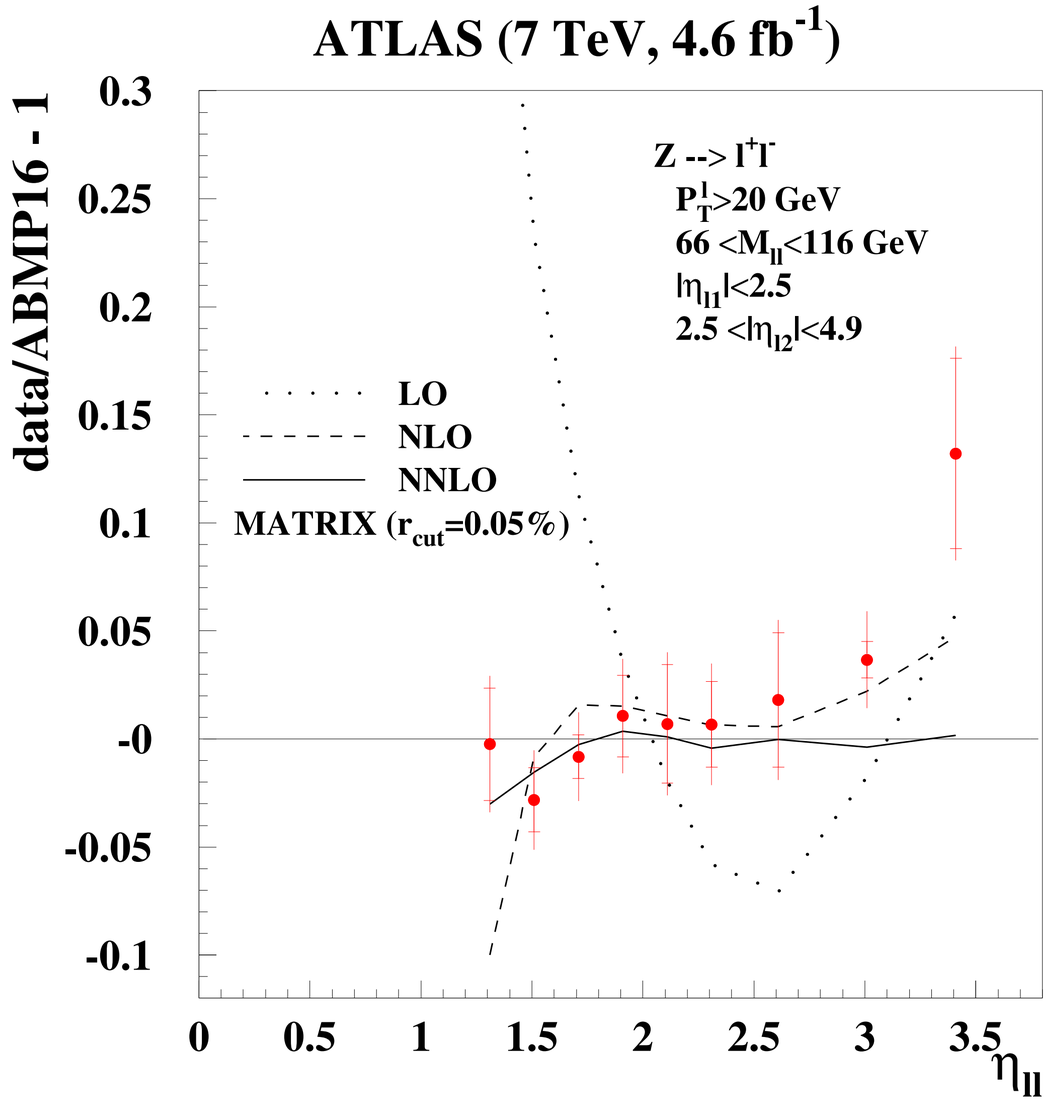
$$\Delta\sigma^{\text{linPCs}}(r_{\text{cut}}) = \int d\Phi_F \int_{\epsilon}^{r_{\text{cut}}} dr' \left(\frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F^{\text{rec}}) - \frac{d\sigma^{\text{CT}}}{d\Phi_F dr'} \Theta_{\text{cuts}}(\Phi_F) \right),$$

based on observation: linPCs described by recoil [Ebert, Michel, Stewart, Tackmann '21]

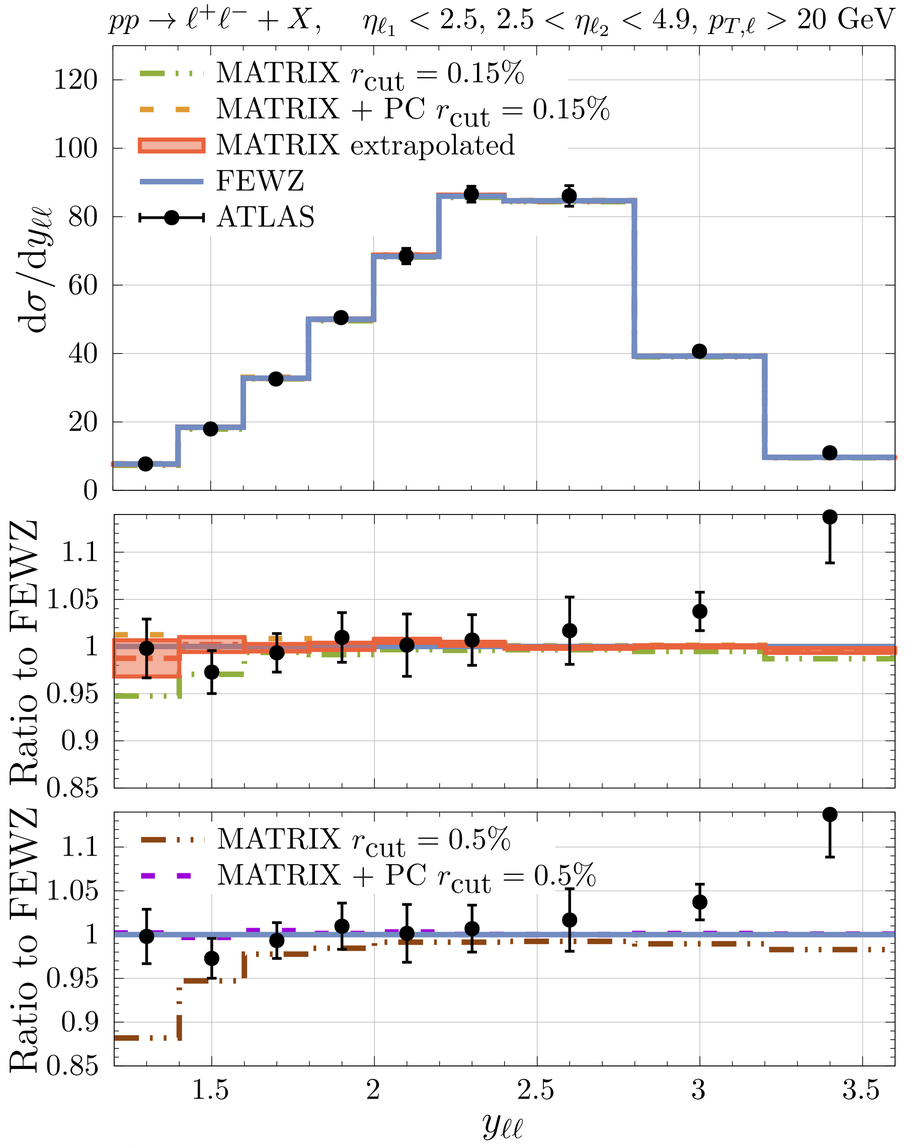




[Alekhin, Kardos, Moch, Trócsányi '21]

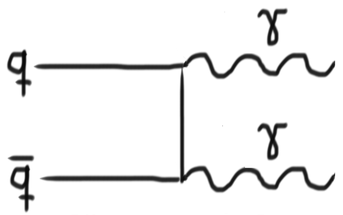


[Buonocore, Kallweit, Rottolli, MW '21]

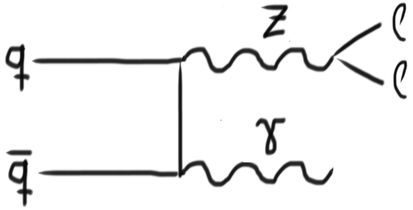


Beyond NNLO QCD for VV in MATRIX

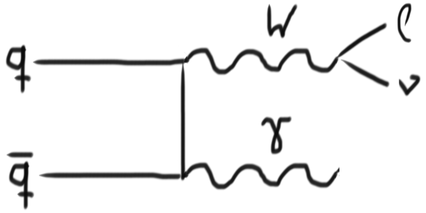
NNLO QCD



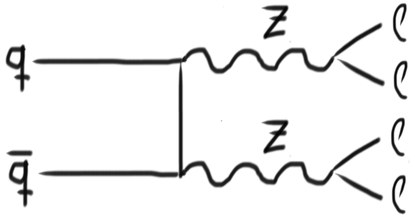
[Catani, et al. '11],
[Grazzini, Kallweit, MW '17]



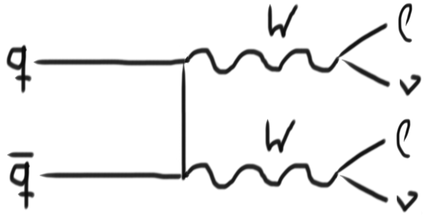
[Grazzini, Kallweit, Rathlev '15],
[Campbell, Neumann, Williams '17]



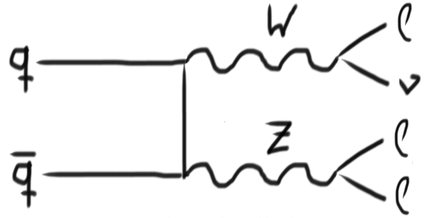
[Grazzini, Kallweit, Rathlev '15]



on-shell + inclusive:
[Cascioli et al. '14], [Heinrich et al. '17]
off-shell + differential:
[Kallweit, MW '18],
[Grazzini, Kallweit, Rathlev '15]



on-shell + inclusive:
[Gehrmann et al. '14]
off-shell + differential:
[Grazzini, Kallweit, Pozzorini,
Rathlev, MW '16]



on-shell & off-shell:
[Grazzini, Kallweit, Rathlev, MW '16 '17]

NLO EW

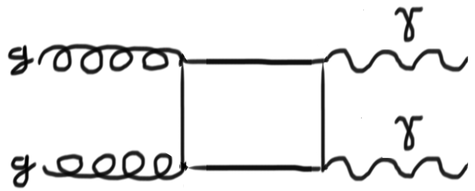
[Bierweiler, Kasprzik, Kühn '13]

[Hollik Meier '04],
[Accomando, Denner, Meier '06]

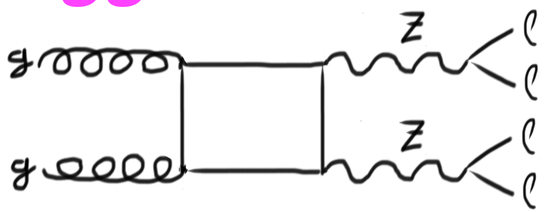
[Accomando, Denner, Meier '06]

on-shell:
[Bierweiler, Kasprzik, Kühn, Uccirati '12], [Bierweiler, Kasprzik, Kühn '13], [Baglio, Ninh, Weber '13]
off-shell:
[Biedermann, Denner, Dittmaier, Hofer, Jäger '16], [Biedermann, Billoni, Denner, Dittmaier, Jäger '16],
[Kallweit, Lindert, Pozzorini, Schönherr '17], [Grazzini, Kallweit, Lindert, Pozzorini, Rathlev, MW '19]

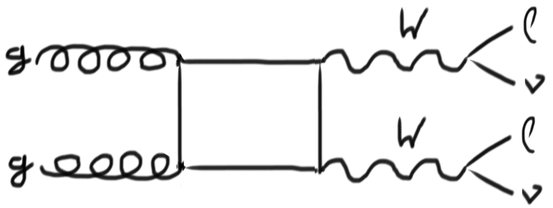
gg NLO QCD



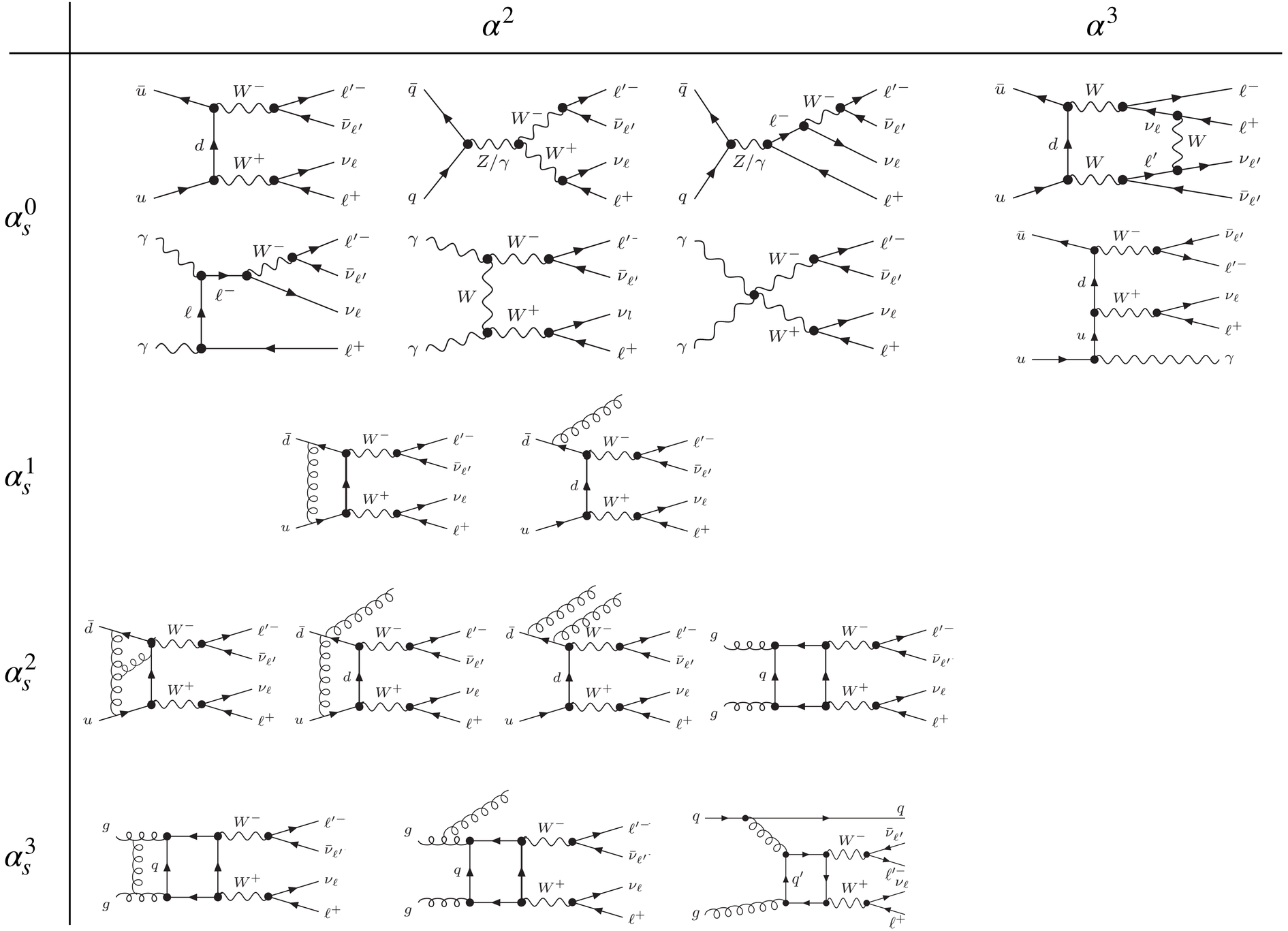
[Bern, Dixon, Schmidt '02]
[Campbell, Ellis, Williams '11]

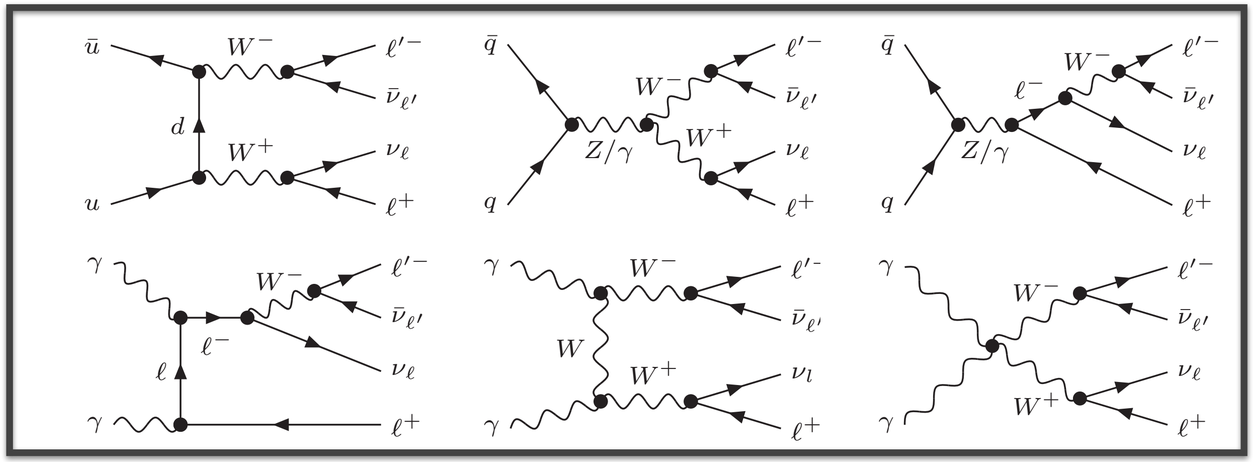


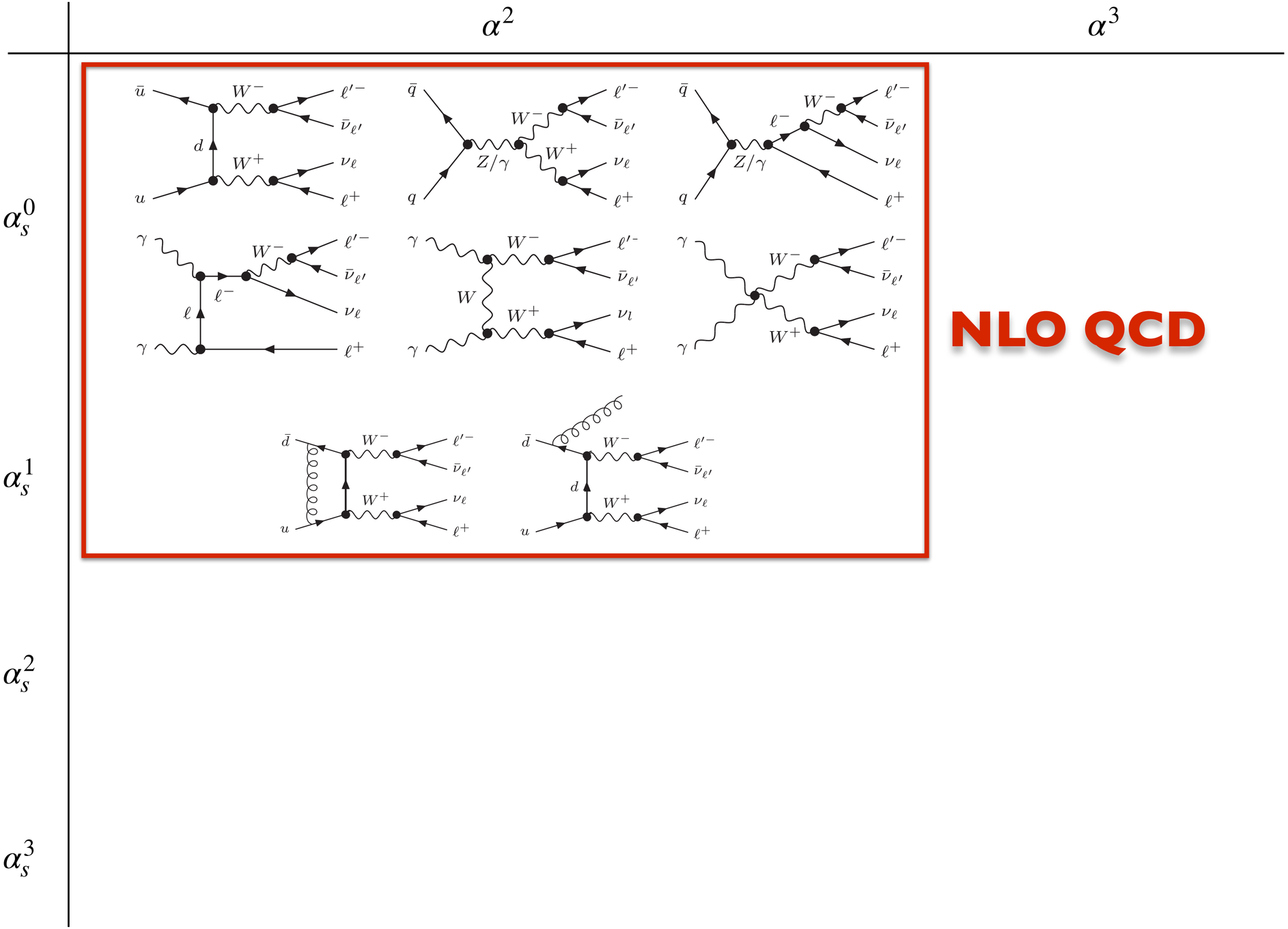
[Caola, Melnikov, Röntsch, Tancredi '15],
[Grazzini, Kallweit, MW, Yook '18 '21]

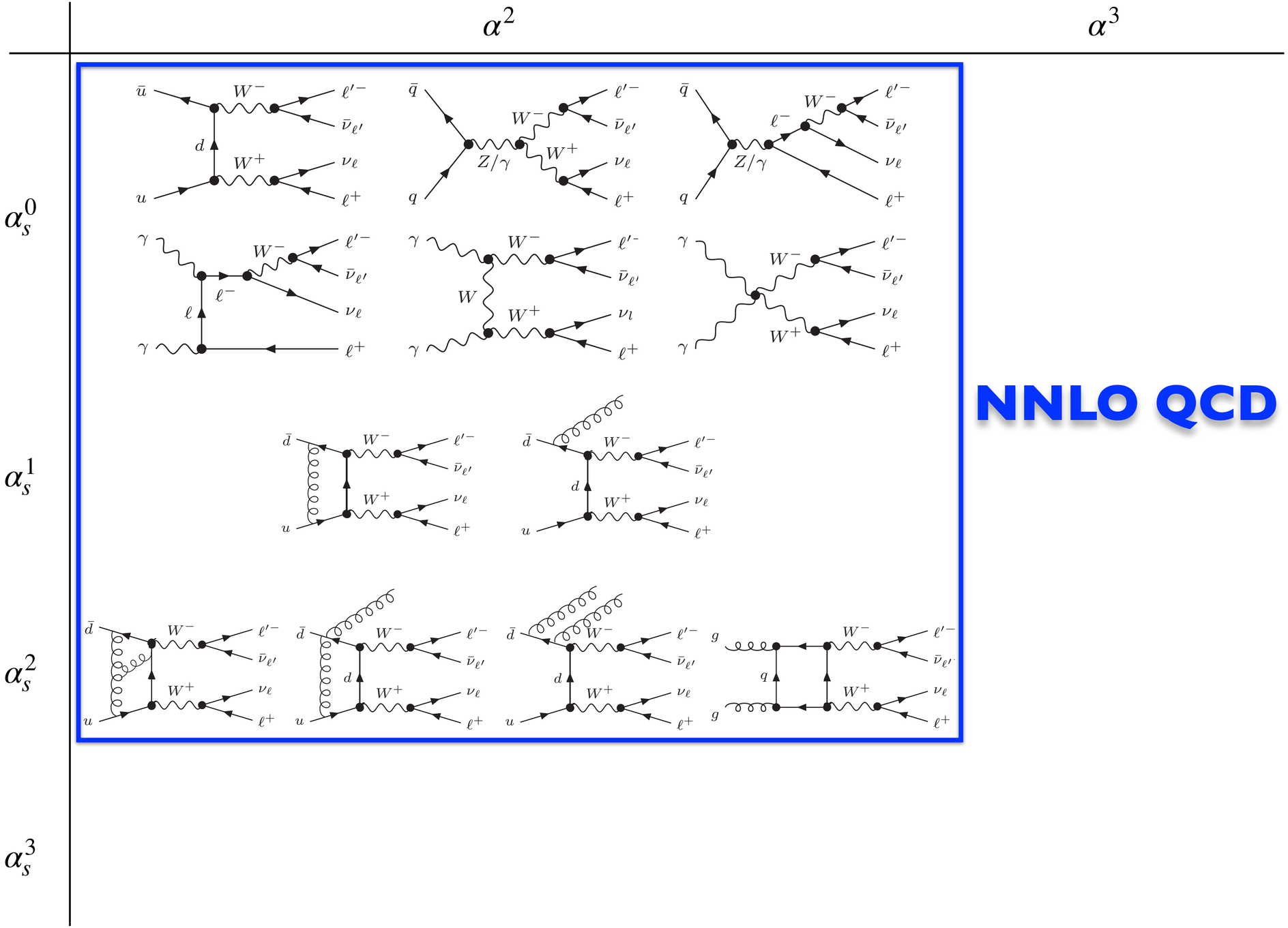


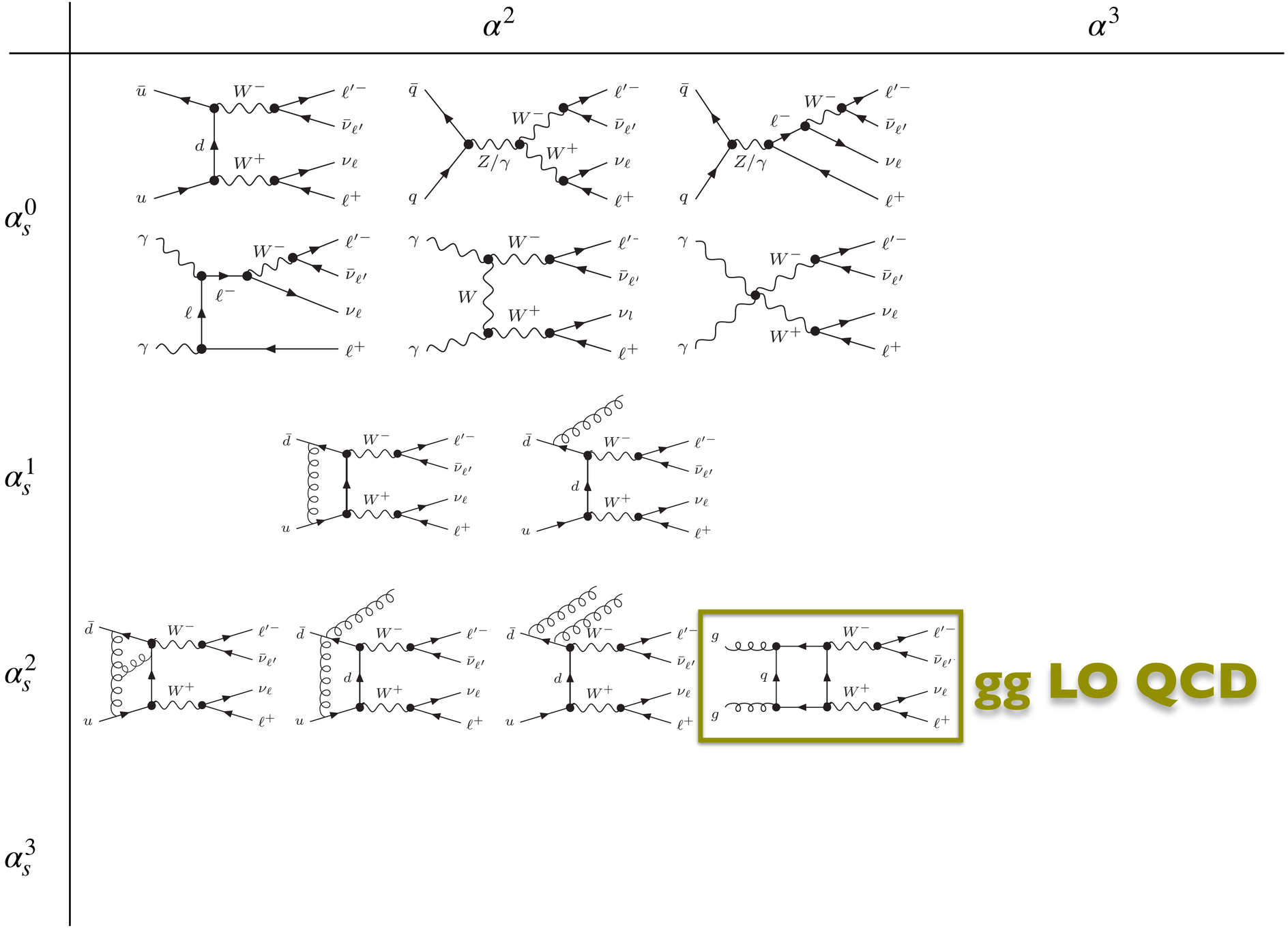
[Caola, Melnikov, Röntsch, Tancredi '15],
[Grazzini, Kallweit, MW, Yook '20]

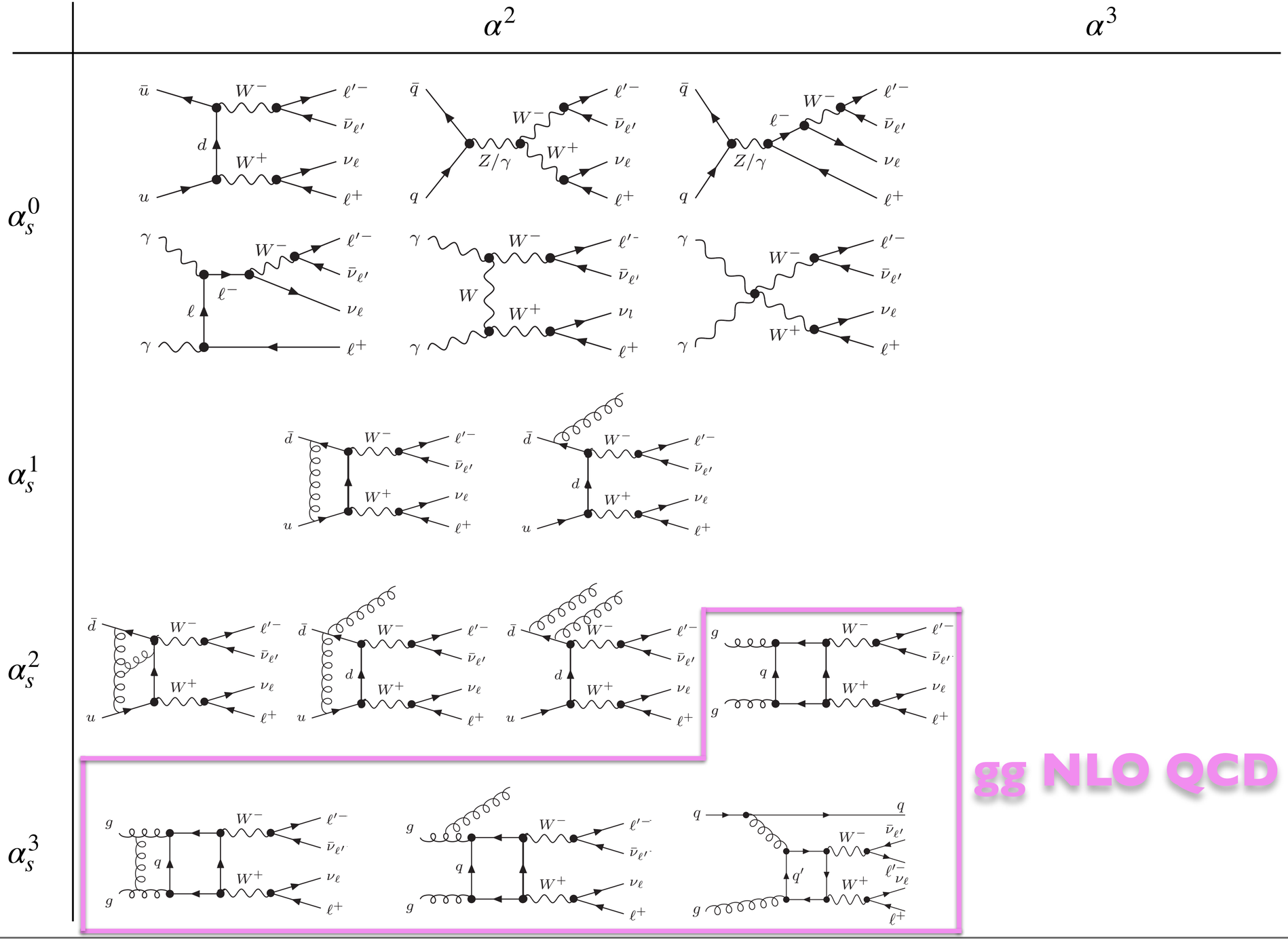

α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
$\bar{u}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
$\bar{q}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ Z/γ W^+ ν_ℓ q ℓ^+
$\bar{q}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ ℓ^- Z/γ ν_ℓ q ℓ^+
$\bar{u}$ W ℓ^- ν_ℓ W ℓ^+ d W ℓ' $\nu_{\ell'}$ u $\bar{\nu}_{\ell'}$
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ ℓ^- ℓ ν_ℓ γ ℓ^+
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ W W^+ ν_l γ ℓ^+
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ ν_ℓ W^+ γ ℓ^+
$\bar{u}$ W^- $\bar{\nu}_{\ell'}$ ℓ'^- d W^+ ν_ℓ u ℓ^+ u γ
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ W^+ ν_ℓ u ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
g W^- ℓ'^- $\bar{\nu}_{\ell'}$ q W^+ ν_ℓ g ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ W^+ ν_ℓ u ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
g W^- ℓ'^- $\bar{\nu}_{\ell'}$ q W^+ ν_ℓ g ℓ^+
g W^- ℓ'^- $\bar{\nu}_{\ell'}$ q W^+ ν_ℓ g ℓ^+
q q W^- $\bar{\nu}_{\ell'}$ q' ℓ'^- W^+ ν_ℓ g ℓ^+

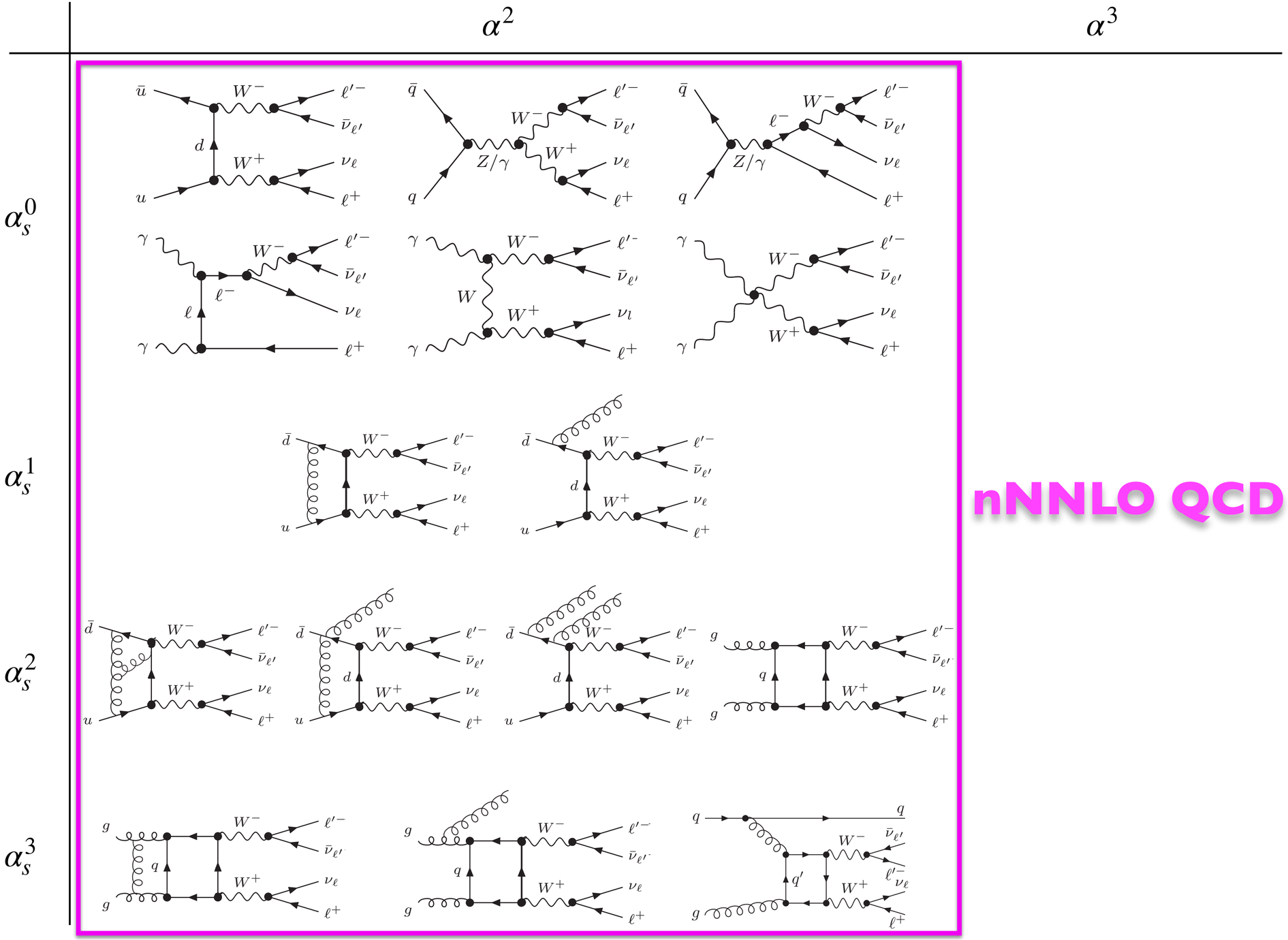
	α^2	α^3
α_s^0		**LO**
α_s^1		
α_s^2		
α_s^3		

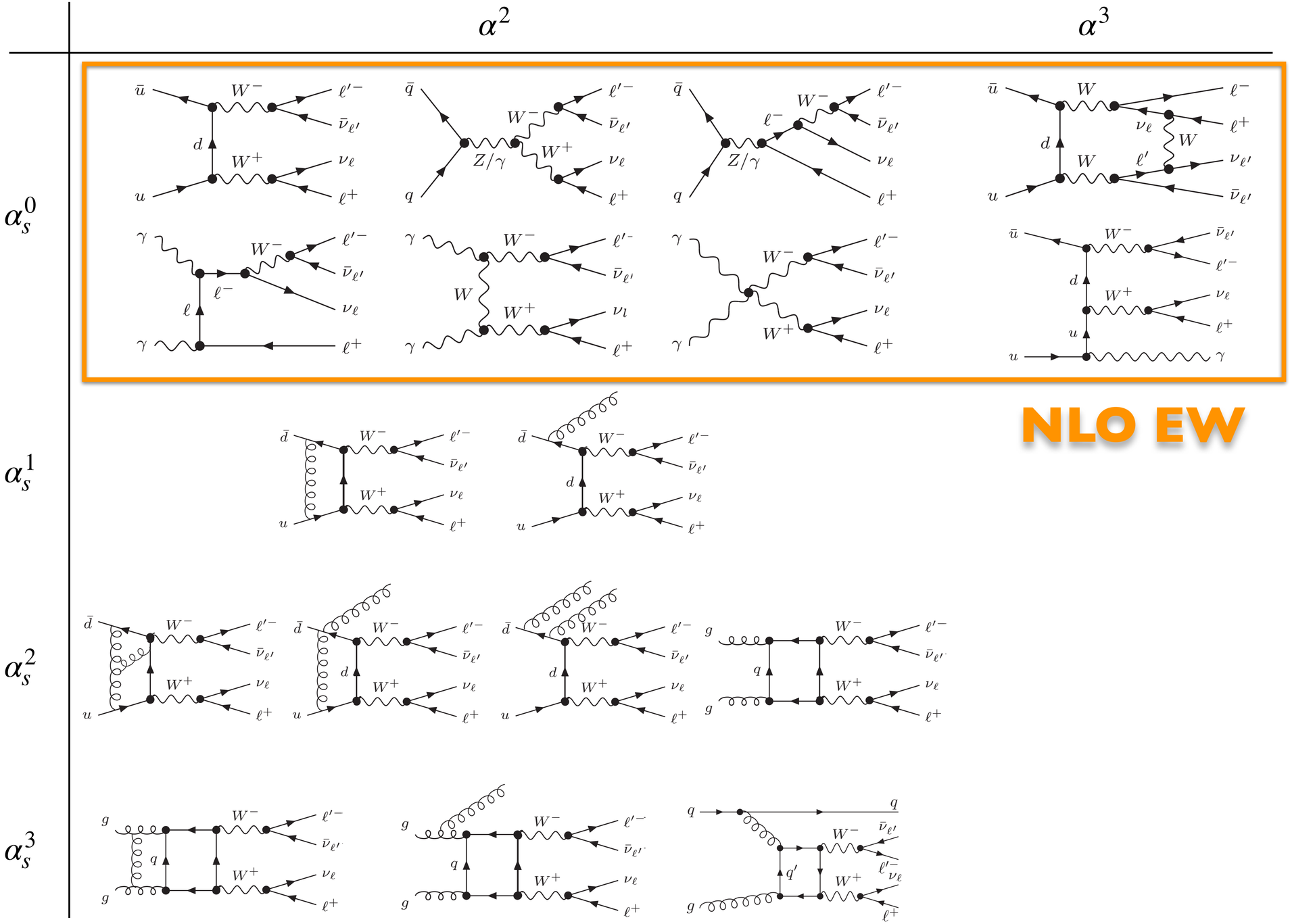

α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
$\bar{u}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
$\bar{q}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ Z/γ W^+ ν_ℓ q ℓ^+
$\bar{q}$ W^- ℓ^- ℓ'^- $\bar{\nu}_{\ell'}$ Z/γ ν_ℓ q ℓ^+
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ ℓ^- ℓ ν_ℓ γ ℓ^+
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ W W^+ ν_l γ ℓ^+
γ W^- ℓ'^- $\bar{\nu}_{\ell'}$ ν_ℓ W^+ γ ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ W^+ ν_ℓ u ℓ^+
$\bar{d}$ W^- ℓ'^- $\bar{\nu}_{\ell'}$ d W^+ ν_ℓ u ℓ^+
NLO QCD

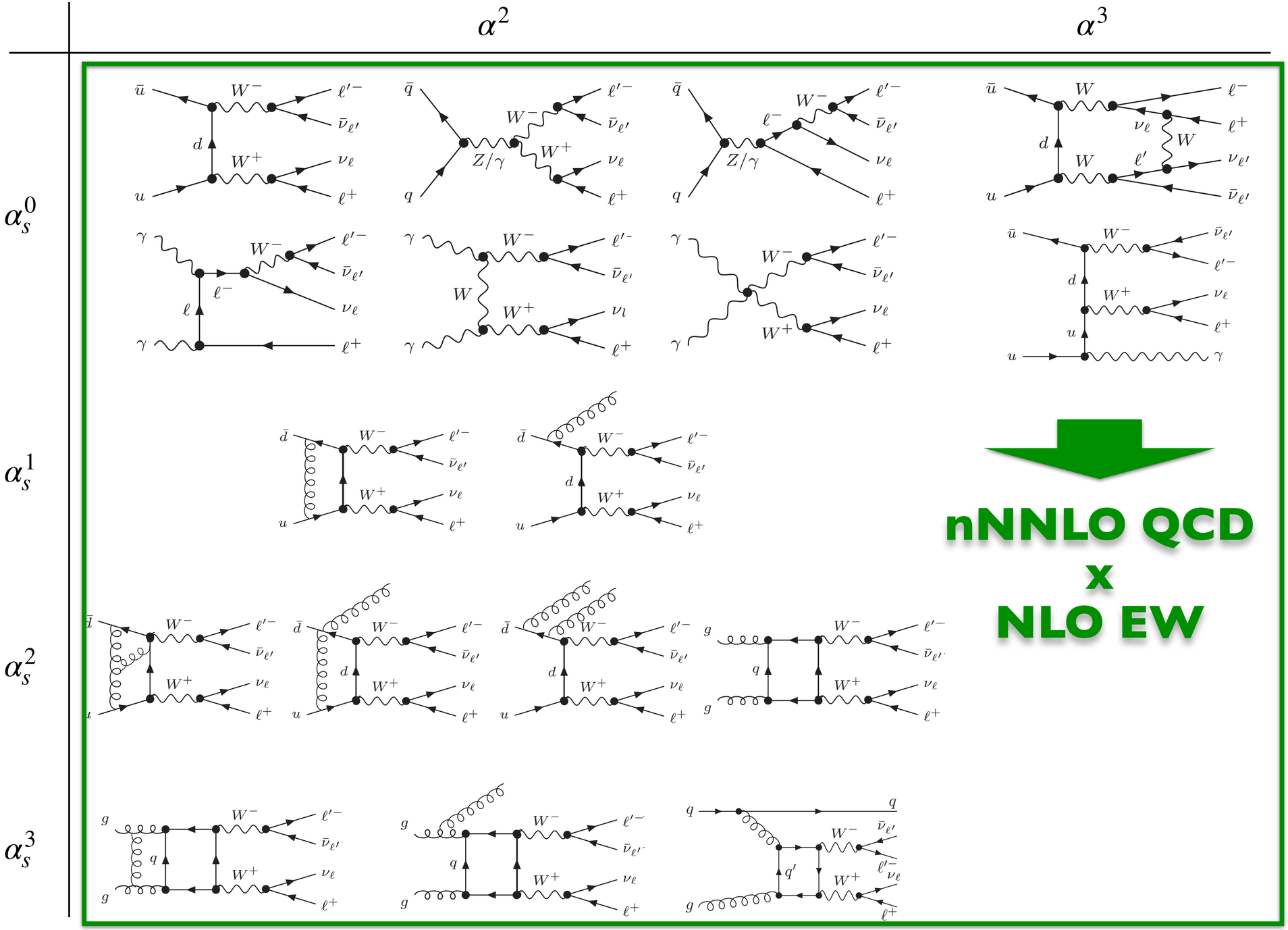

α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
NNLO QCD


α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
gg LO QCD


α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
gg NLO QCD


α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
nNNLO QCD


α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
NLO EW


α^2
α^3
α_s^0
α_s^1
α_s^2
α_s^3
nNNLO QCD
x
NLO EW

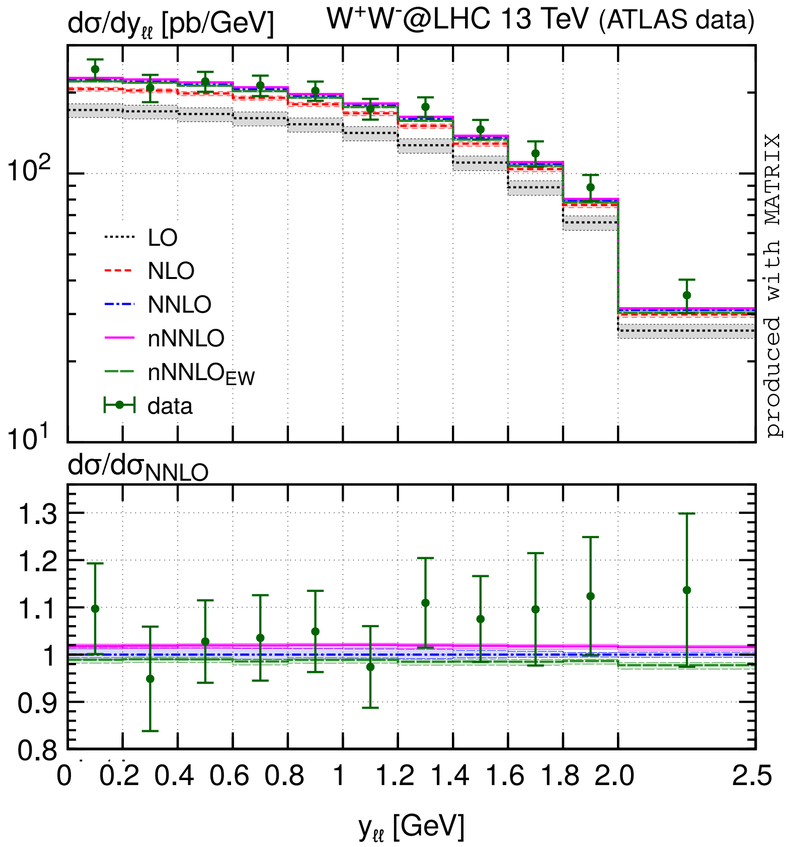
Example 1: pp → 2ℓ2ν (WW)

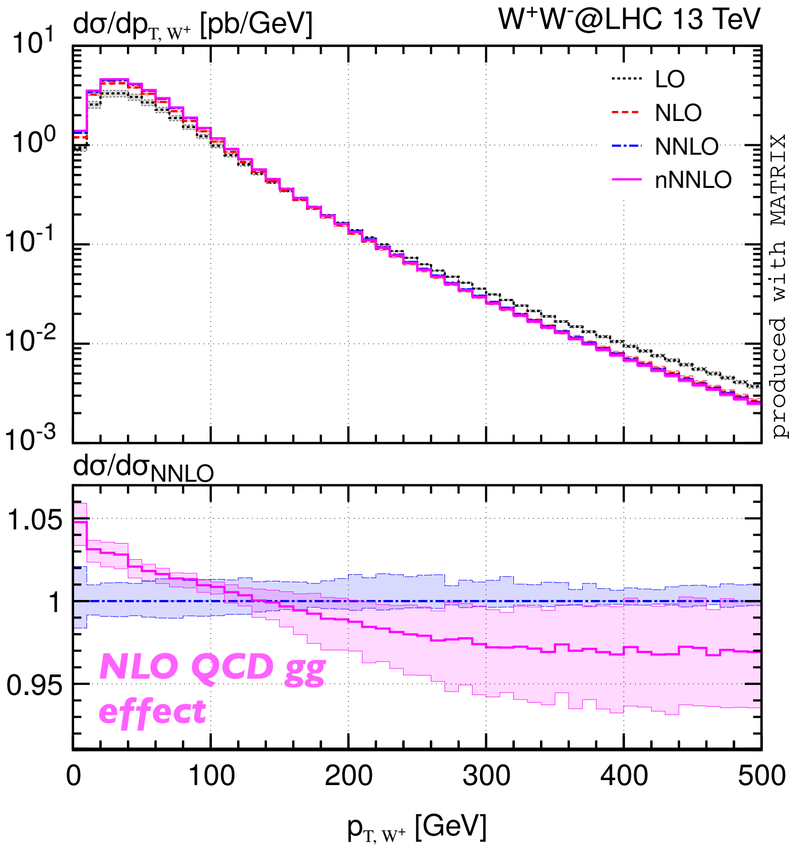
NNLO QCD × **gg NLO QCD** × **NLO EW**

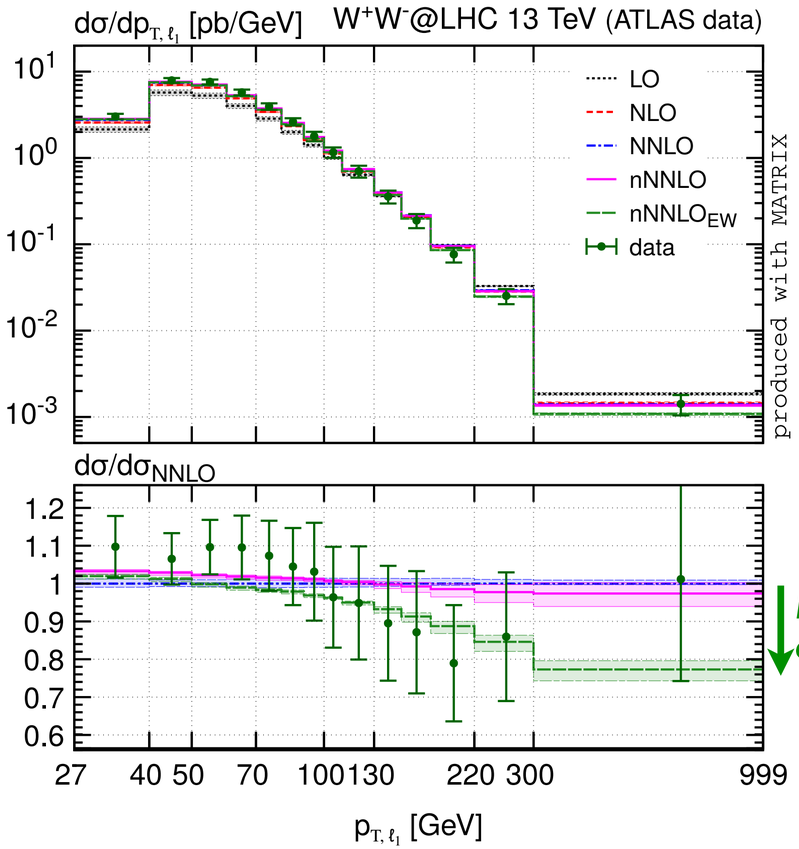
ZZ, WW, WZ
→ [various calculations within MATRIX]

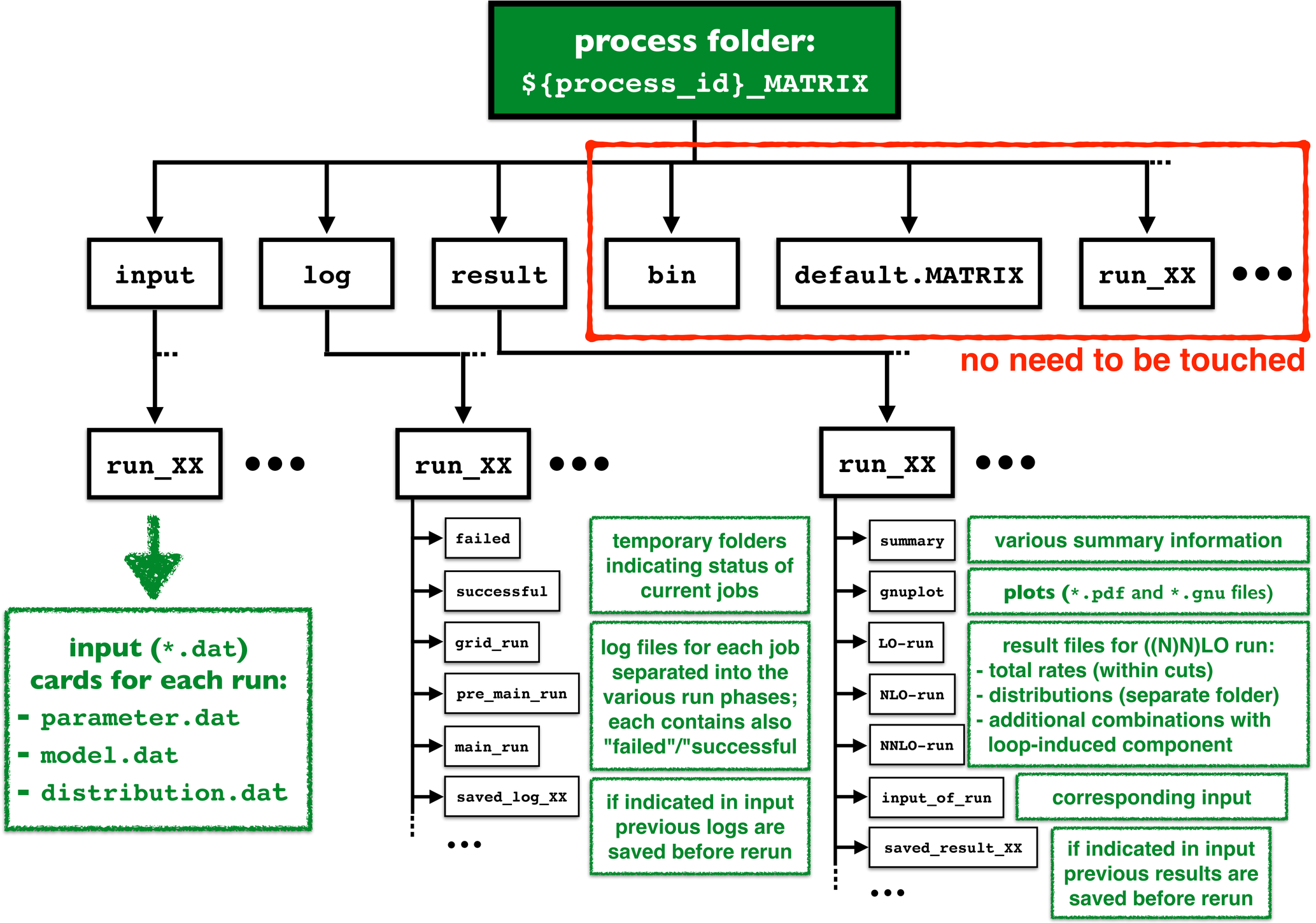
ZZ → [Grazzini, Kallweit, MW, Yook '18]
WW → [Grazzini, Kallweit, MW, Yook '20]

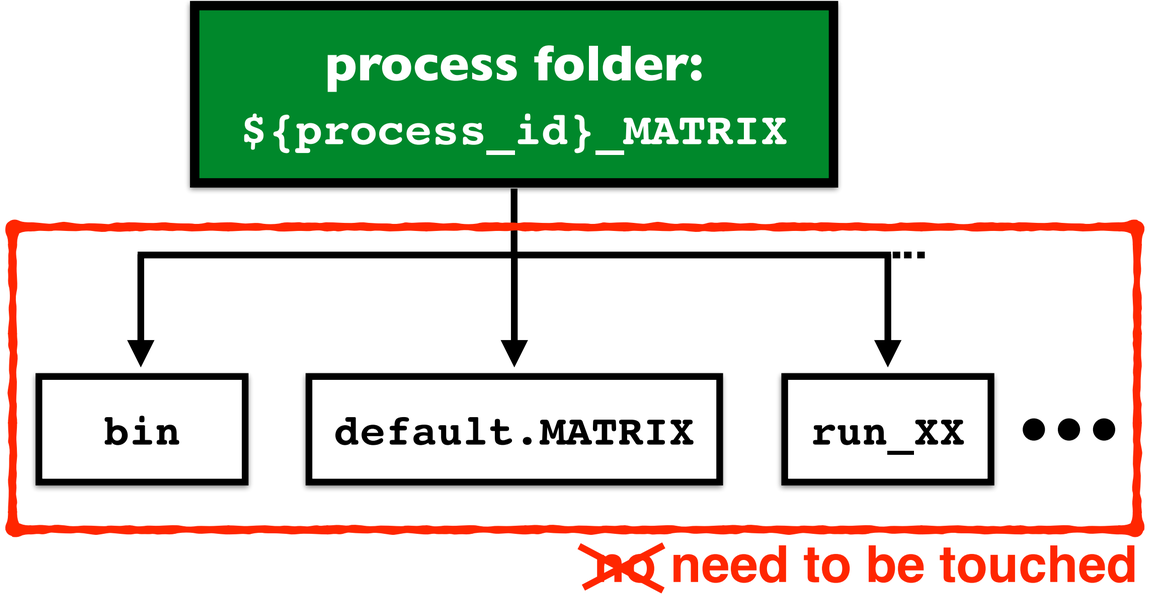
ZZ, WW, WZ
→ [Grazzini, Kallweit, Lindert, Pozzorini, MW '19]



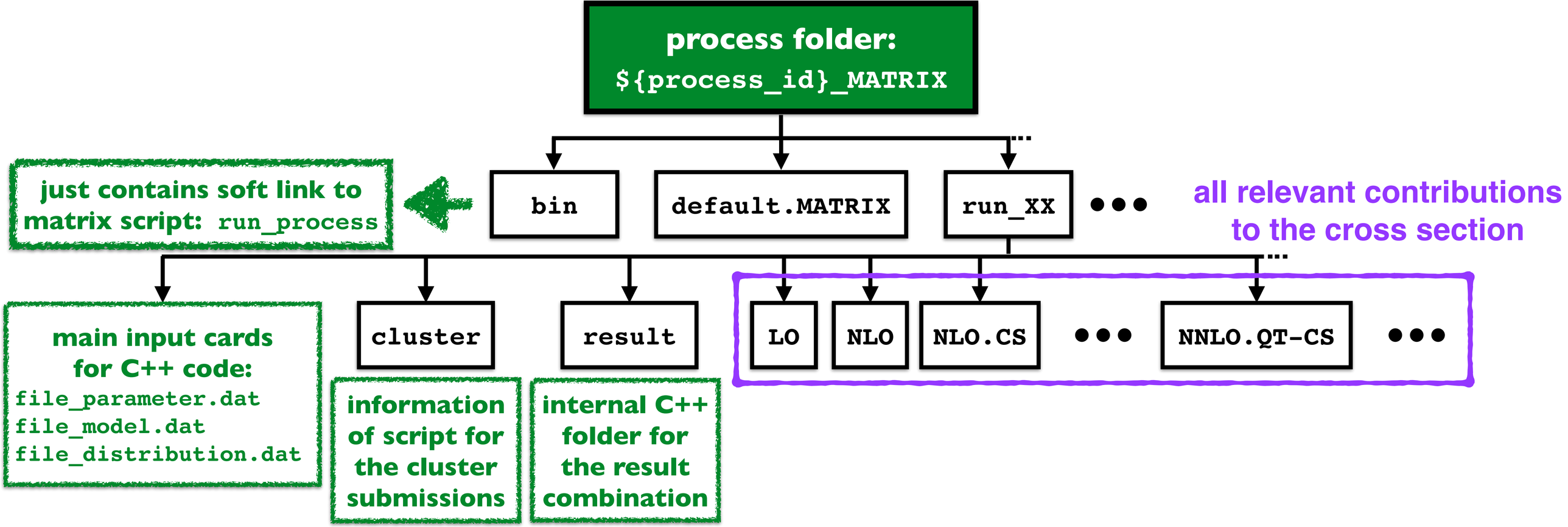


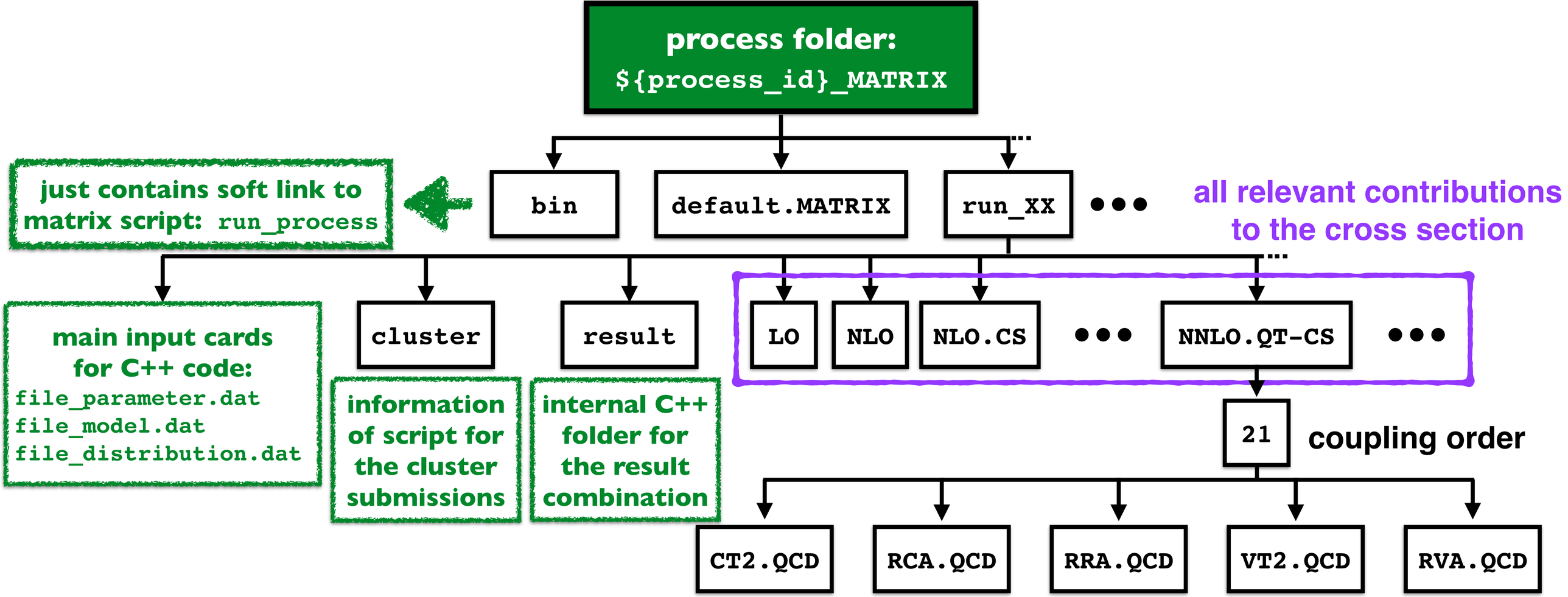



process folder:
${process_id}_MATRIX
input
log
result
bin
default.MATRIX
run_XX
no need to be touched
run_XX
run_XX
run_XX
input (*.dat)
cards for each run:
- parameter.dat
- model.dat
- distribution.dat
failed
successful
grid_run
pre_main_run
main_run
saved_log_XX
temporary folders indicating status of current jobs
log files for each job separated into the various run phases; each contains also "failed"/"successful
if indicated in input previous logs are saved before rerun
summary
gnuplot
LO-run
NLO-run
NNLO-run
input_of_run
saved_result_XX
various summary information
plots (*.pdf and *.gnu files)
result files for ((N)N)LO run:
- total rates (within cuts)
- distributions (separate folder)
- additional combinations with loop-induced component
corresponding input
if indicated in input previous results are saved before rerun



… to actually do anything useful,
but just plain running …


process folder:
${process_id}_MATRIX
just contains soft link to matrix script: run_process
bin
default.MATRIX
run_XX
all relevant contributions to the cross section
main input cards for C++ code:
file_parameter.dat
file_model.dat
file_distribution.dat
cluster
information of script for the cluster submissions
result
internal C++ folder for the result combination
LO
NLO
NLO.CS
NNLO.QT-CS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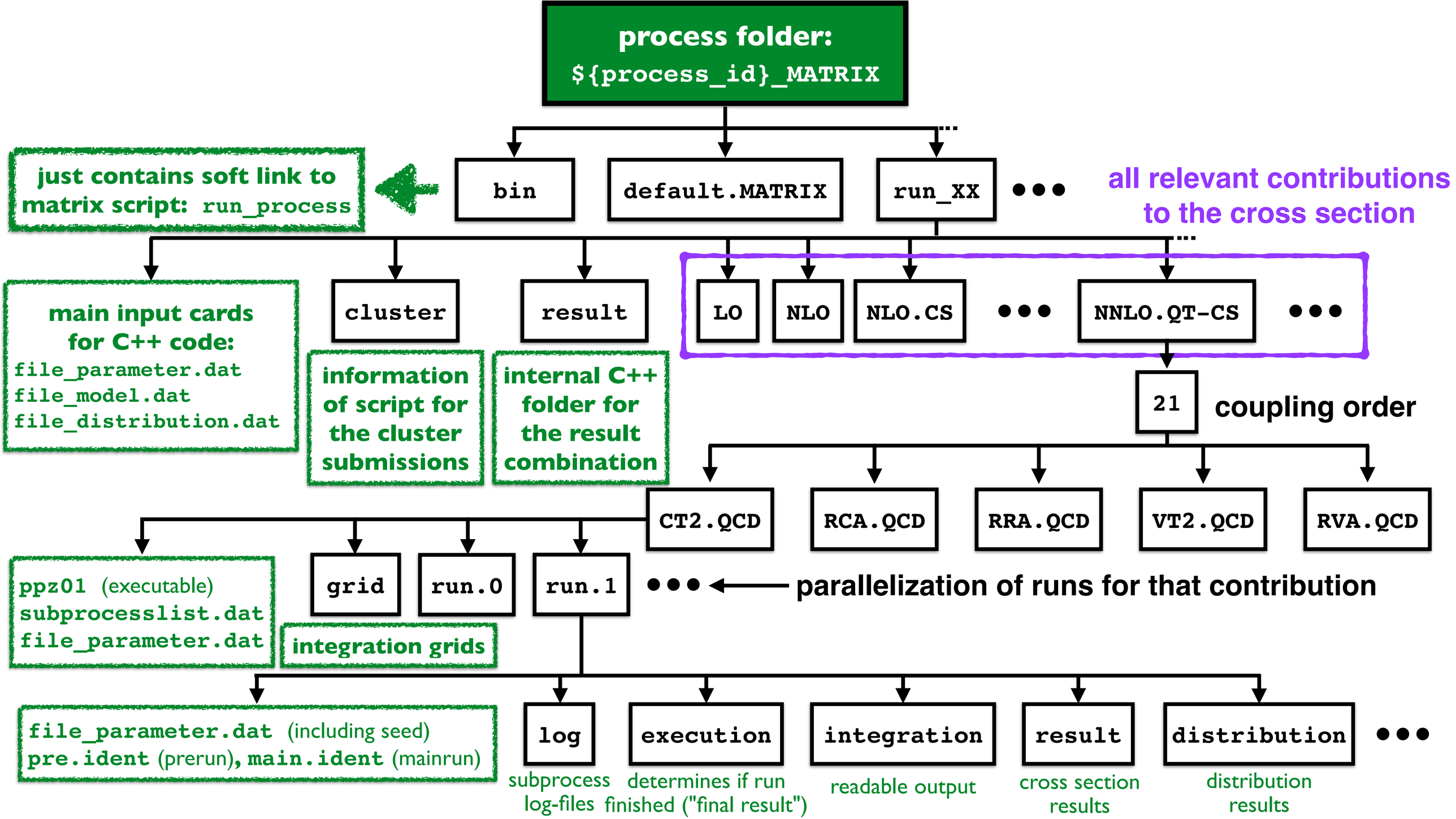
coupling order
CT2.QCD
RCA.QCD
RRA.QCD
VT2.QCD
RVA.QCD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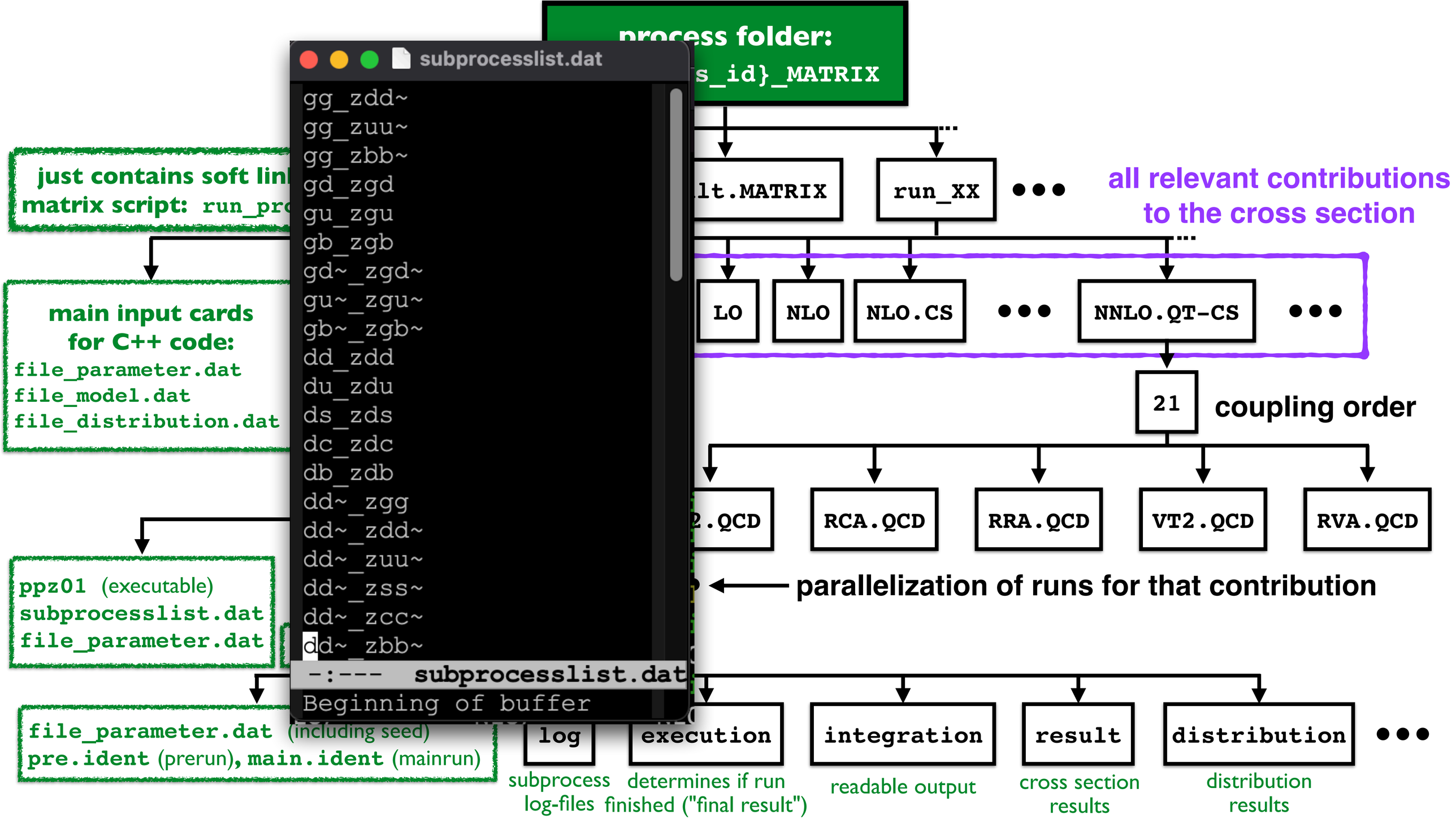
ppz01 (executable)
subprocesslist.dat
file_parameter.dat
grid
integration grids
run.0
run.1
parallelization of runs for that contribution
file_parameter.dat (including seed)
pre.ident (prerun), main.ident (mainrun)
log
subprocess log-files
execution
determines if run finished ("final result")
integration
readable output
result
cross section results
distribution
distribution results


process folder:
s_id}_MATRIX
subprocesslist.dat
gg_zdd~
gg_zuu~
gg_zbb~
gd_zgd
gu_zgu
gb_zgb
gd~_zgd~
gu~_zgu~
gb~_zgb~
dd_zdd
du_zdu
ds_zds
dc_zdc
db_zdb
dd~_zgg
dd~_zdd~
dd~_zuu~
dd~_zss~
dd~_zcc~
dd~_zbb~
-:--- subprocesslist.dat
Beginning of buffer
just contains soft lin
matrix script: run_pr
main input cards
for C++ code:
file_parameter.dat
file_model.dat
file_distribution.dat
ppz01 (executable)
subprocesslist.dat
file_parameter.dat
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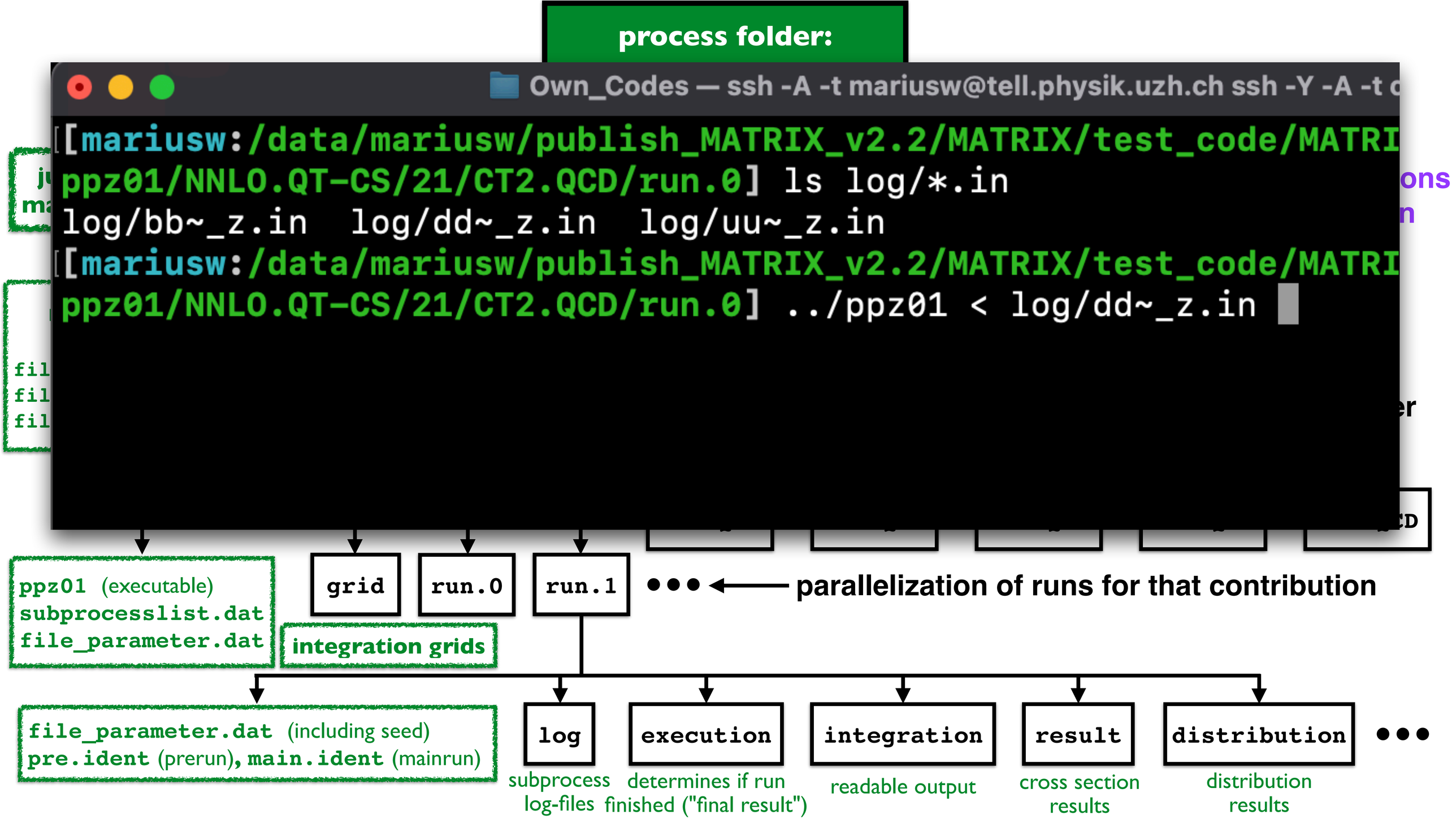
process folder:
Own_Codes — ssh -A -t mariusw@tell.physik.uzh.ch ssh -Y -A -t c
[mariusw:/data/mariusw/publish_MATRIX_v2.2/MATRIX/test_code/MATRI
ppz01/NNLO.QT-CS/21/CT2.QCD/run.0] ls log/*.in
log/bb~_z.in log/dd~_z.in log/uu~_z.in
[mariusw:/data/mariusw/publish_MATRIX_v2.2/MATRIX/test_code/MATRI
ppz01/NNLO.QT-CS/21/CT2.QCD/run.0] ../ppz01 < log/dd~_z.in
ppz01 (executable)
subprocesslist.dat
file_parameter.dat
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parallelization of runs for that contribution
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cross section results
distribution
distribution results

process folder:

Own_Codes — ssh -A -t mariusw@tell.physik.uzh.ch ssh -Y -A -t c

```
[mariusw:/data/mariusw/publish_MATRIX_v2.2/MATRIX/test_code/MATRI
ppz01/NNLO.QT-CS/21/CT2.QCD/run.0] ls log/*.in
log/bb~_z.in  log/dd~_z.in  log/uu~_z.in
[mariusw:/data/mariusw/publish_MATRIX_v2.2/MATRIX/test_code/MATRI
ppz01/NNLO.QT-CS/21/CT2.QCD/run.0] ../ppz01 < log/dd~_z.in
BEGIN
munich::walltime_start: Thu Feb  1 19:35:32 2024

event_set::initialization_input: (event_set::output_particle_defi
```

ppz01 (executable)
subprocesslist.dat
file_parameter.dat

grid

run.0

run.1

●●● ← parallelization of runs for that contribution

integration grids

file_parameter.dat (including seed)
pre.ident (prerun), **main.ident** (mainrun)

log
subprocess log-files

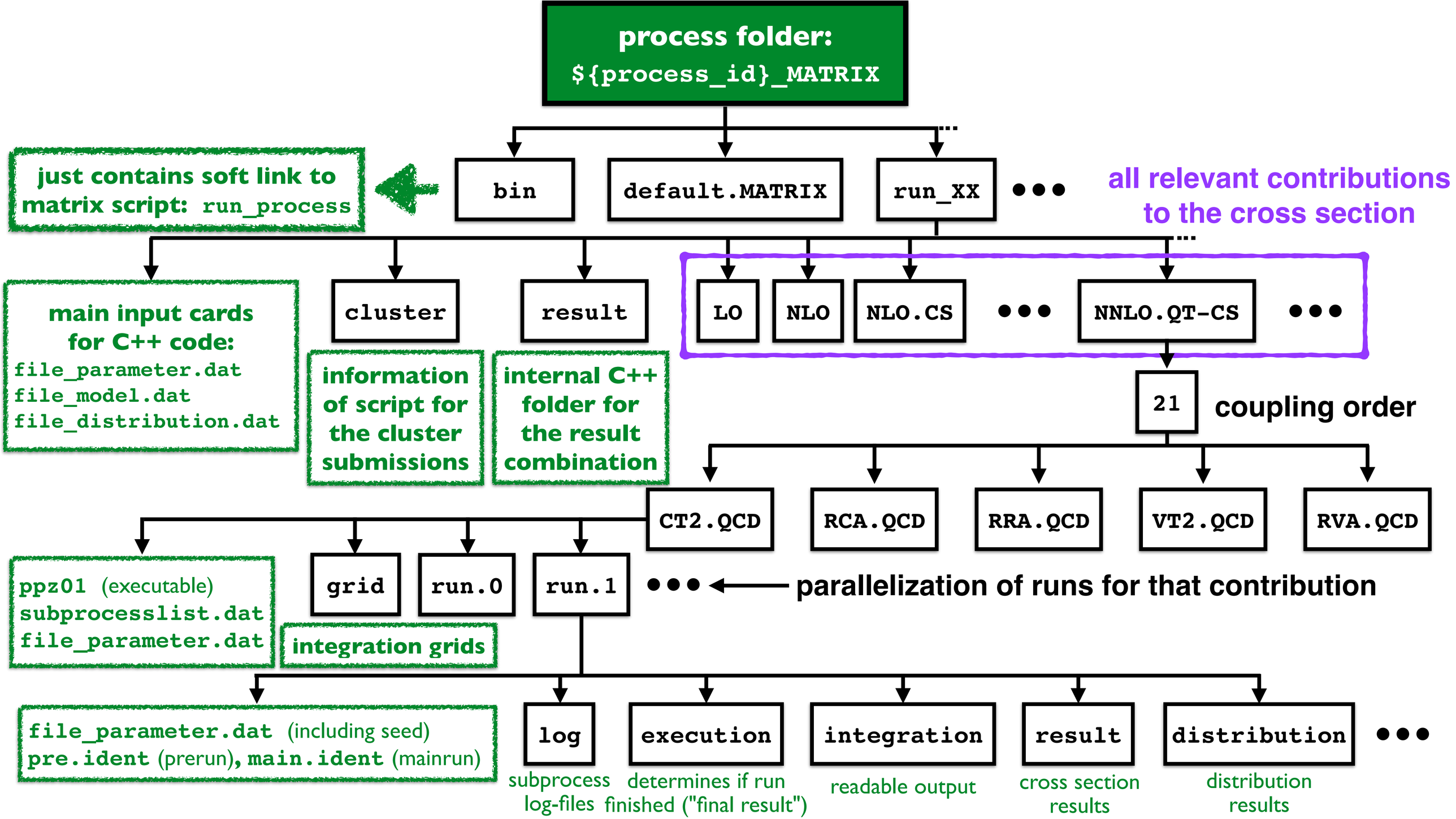
execution
determines if run finished ("final result")

integration
readable output

result
cross section results

distribution
distribution results

●●●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Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

- imports
- global definitions
- read command line arguments
  - read `config/MATRIX_configuration` & set paths
  - interactive shell (figure out `${process_id}`)
  - license agreement
- create input file (for current or all processes)
- main compilation
  - ➙ install amplitude provider (OpenLoops, Recola, …)
  - ➙ install external libraries (tdhpl, cln, ginac, VVamp, …)
  - ➙ create `Makefile` and compile process
  - ➙ download OpenLoops amplitudes
- create process folder `run/${process_id}_MATRIX`

takes care of the entire compilation & setup of the code to be run

quite compact: just ~ 420 lines

Structure of the Matrix scripts

${MATRIX_folder}/matrix

imports

```
sys.path.append(pjoin(os.path.dirname(os.path.realpath(__file__)),"bin/modules"))
from initialize_classes_matrix import *
```

${MATRIX_folder}/bin/modules/initialize_classes_matrix.py

${MATRIX_folder}/bin/modules/handle_*.py

```
MATRIX — -bash — 95×69
[mars:~/Uni/Own_Codes/publish_MATRIX_v2.1.0/MATRIX] ls bin/modules/*py
bin/modules/combine_distributions.py     bin/modules/handle_lhapdf.py
bin/modules/combine_results.py           bin/modules/handle_log.py
bin/modules/custom_WW_gnuplot.py         bin/modules/handle_output.py
bin/modules/handle_cluster.py            bin/modules/handle_process.py
bin/modules/handle_folder.py             bin/modules/handle_process_folder.py
bin/modules/handle_gnuplot.py            bin/modules/handle_result.py
bin/modules/handle_input.py              bin/modules/initialize_classes.py
bin/modules/handle_input_files.py        bin/modules/initialize_classes_matrix.py
bin/modules/handle_input_matrix.py
[mars:~/Uni/Own_Codes/publish_MATRIX_v2.1.0/MATRIX]
```

${MATRIX_folder}/bin/modules/handle_process.py

➙ contains main class for matrix compilation

${MATRIX_folder}/bin/modules/handle_input_files.py

➙ creates input files for each process:
`(file_)parameter.dat`, `(file_)model.dat`, `(file_)distribution.dat`
inside `$MATRIX_folder/run/run/input_files/${process_id}`

Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

imports

global definitions

- define existing processes and their description

```
process_name.process_description["pph21"] = "on-shell Higgs production"
process_name.process_description["ppz01"] = "on-shell Z production"
...
```

- define relevant OpenLoops amplitudes

```
# define amplitudes to be downloaded+compiled from OpenLoops
openloops_amplitudes_dict = {}
openloops_amplitudes_dict["pph21"] = ["heftpphj"]
openloops_amplitudes_dict["ppz01"] = ["ppvj","ppvj_ew"]
...
```

- define order of printout

```
# change order of processes printed on screen
process_name.process_order = ["pph21","ppz01","ppw01","ppwx01","ppeex02","ppnenex02"
,"ppenex02","ppexne02","ppaa02","ppeexa03","ppnenexa03","ppenexa03","ppexnea03","ppz
z02","ppwxw02","ppemexmx04","ppeeexex04","ppeexnmnmx04","ppemxnmnex04","ppeexnenex04
", "ppemexnmx04","ppeeexnex04","ppeexmxnm04","ppeexexne04","ppttx20","ppaaa03"]
```

- set requirements (tdhpl,VVamp, …)

```
tdhpl_processes = ["ppeexa03","ppnenexa03","ppexnea03","ppenexa03","ppttx20", "ppbbx
20"]
qqVVamp_processes = ["ppemexmx04","ppeeexex04","ppeexnmnmx04","ppemxnmnex04","ppeexn
enex04","ppemexnmx04","ppeeexnex04","ppeexmxnm04","ppeexexne04"]
# until fixed in Makefile WZ needs to compile ggVVamp amplitude
ggVVamp_processes = qqVVamp_processes
process_name.available_processes=copy.copy(process_name.process_order)
```

Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

imports

global definitions

read command line arguments

read `config/MATRIX_configuration` & set paths

interactive shell (figure out `${process_id}`)

license agreement

Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

imports

global definitions

read command line arguments

read `config/MATRIX_configuration` & set paths

interactive shell (figure out `${process_id}`)

license agreement

create input file (for current or all processes)

- default input: **`${MATRIX_folder}/config/process_inputs.py`**

process_inputs.py

```
#{{{ header...
#{{{ pph21 input...
#{{{ ppz01 input
proc_dict["ppz01"]["process_class"] = "pp-z+X"
proc_dict["ppz01"]["scale_ren"] = "91.1876"
proc_dict["ppz01"]["scale_fact"] = "91.1876"
proc_dict["ppz01"]["dynamic_scale"] = "0"
proc_dict["ppz01"]["factor_central_scale"] = "1"
scale_dict["ppz01"] = ['0: fixed scale above', '1: invariant mass
(Q) of system (of the colourless final states)', '2: transverse ma
ss (mT^2=Q^2+pT^2) of system (of the colourless final states)']
cuts_dict["ppz01"]["block"] = ['jet']
cuts_dict["ppz01"]["user"] = []
#}}}
#{{{ ppw01 input...
```

- **`${MATRIX_folder}/bin/modules/handle_input_files.py`**
  → creates `(file_)parameter/model/distribution.dat` inside `$MATRIX_folder/run/run/input_files/${process_id}`

- create input files for all processes:

  `./matrix ppz01 –clean_create_input_file`

Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

imports

global definitions

read command line arguments

read `config/MATRIX_configuration` & set paths

interactive shell (figure out `${process_id}`)

license agreement

create input file (for current or all processes)

main compilation

- ➙ install amplitude provider (OpenLoops, Recola, …)
- ➙ install external libraries (tdhpl, cln, ginac, VVamp, …)
- ➙ create `Makefile` and compile process
- ➙ download OpenLoops amplitudes

- **`${MATRIX_folder}/bin/modules/handle_process.py`**

handle_process.py

```
#{{{ class: compile_process()
class compile_process():
#{{{ def: __init__(self,process_in,matrix_dir_in,nr_cores_in)...
#{{{ def: create_makefile(self)
    def create_makefile(self):
        if self.do_resum:
            cloud_makefile = pjoin(self.matrix_dir,"Makefile.clean_res")
        else:
            cloud_makefile = pjoin(self.matrix_dir,"Makefile.clean")
        self.makefile = pjoin(self.matrix_dir,"Makefile")
        shutil.copy(cloud_makefile,self.makefile)
        inp.input_change_entry(self.makefile,"MAINPATH",self.matrix_dir)
        inp.input_change_entry(self.makefile,"LHAPDF_CONFIG",self.path_to_lhapdf)
        inp.input_change_entry(self.makefile,"GSL_CONFIG",self.path_to_gsl)
        inp.input_change_entry(self.makefile,"OpenLoops_CONFIG",self.path_to_openloops)
        inp.input_change_entry(self.makefile,"GINAC_DIR",self.ginac_dir)
        inp.input_change_entry(self.makefile,"CLN_DIR",self.cln_dir)
        inp.input_change_entry(self.makefile,"FORTRAN_LIB_PATH",self.libgfortran_dir)
        inp.input_change_entry(self.makefile, "RECOLA_DIR", self.recola_dir)
        inp.input_change_entry(self.makefile, "CHAPLIN_DIR", self.chaplin_dir)
        if self.do_resum:
            inp.input_change_entry(self.makefile,"MOREDIR",self.more_dir)
        inp.input_change_entry(self.makefile,"HOMEPATH",self.matrix_dir)
        if self.process == "ppaaa03":
            inp.input_change_entry(self.makefile, "2LOOP_DIR", self.ppaaa03_2loop_dir)
#}}}
#{{{ def: download_and_compile_openloops(self,in_dir)...
#{{{ def: openloops_compiled(self, path_to_openloops = self.path_to_openloops)...
#{{{ def: download_openloops_amplitudes(self)...
#{{{ def: compile_recola(self,recola_tar)...
#{{{ def: recola_compiled(self, recola_dir = self.recola_dir)...
#{{{ def: mac_make_absolute_path_in_dylib_linking(self,file_path)...
#{{{ def: create_openloops_cfg(self,path)...
#{{{ def: openloops_amplitude_compiled(self, amplitude, path_to_openloops = self.path_to_openloops)...
#{{{ def: compile_MoRe(self,more_tar)...
#{{{ def: MoRe_compiled(self, more_dir = self.more_dir)...
#{{{ def: compile_qqvvamp(self,qqvvamp_tar)...
#{{{ def: qqvvamp_compiled(self, qqvvamp_dir = self.qqvvamp_dir)...
#{{{ def: compile_ggvvamp(self,ggvvamp_tar)...
#{{{ def: ggvvamp_compiled(self, ggvvamp_dir = self.ggvvamp_dir)...
#{{{ def: compile_tdhpl(self,tdhpl_tar)...
#{{{ def: tdhpl_compiled(self, tdhpl_dir = self.tdhpl_dir)...
#{{{ def: compile_ampzz(self,ampzz_tar)...
#{{{ def: ampzz_compiled(self, ampzz_dir = self.ampzz_dir)...
-:**-  handle_process.py   Top (55,0)    Git-master  (Python Fld ElDoc) 11:48am 1.46
```

Structure of the Matrix scripts

`${MATRIX_folder}/matrix`

imports

global definitions

read command line arguments

read `config/MATRIX_configuration` & set paths

interactive shell (figure out `${process_id}`)

license agreement

create input file (for current or all processes)

main compilation

- ➙ install amplitude provider (OpenLoops, Recola, …)
- ➙ install external libraries (tdhpl, cln, ginac, VVamp, …)
- ➙ create `Makefile` and compile process
- ➙ download OpenLoops amplitudes

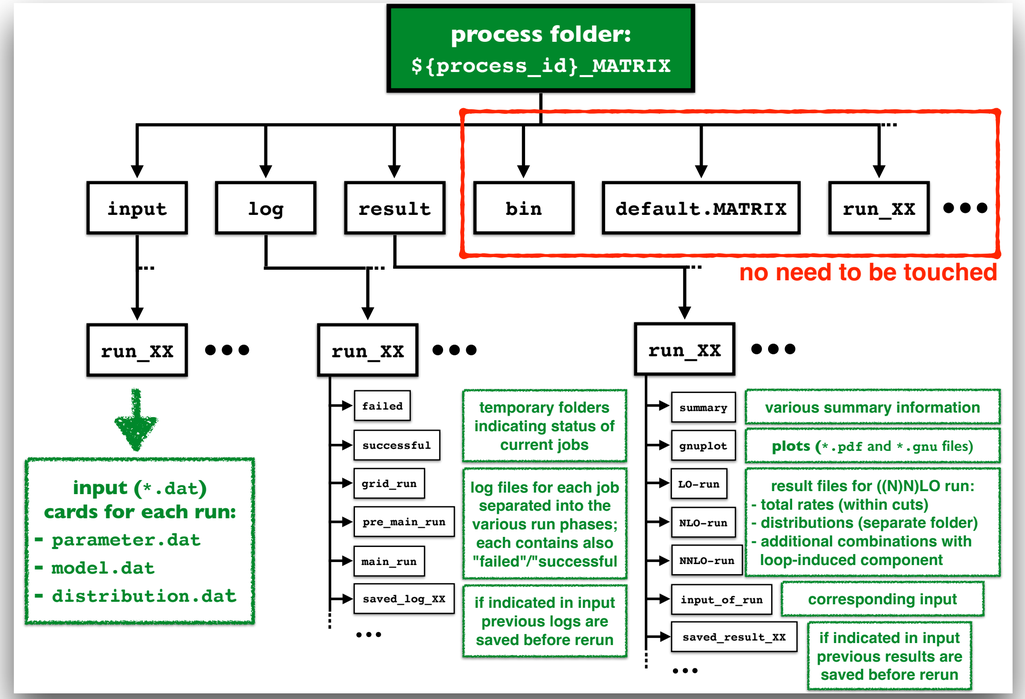
create process folder `run/${process_id}_MATRIX`

- create process folder

  `${MATRIX_folder}/run/${process_id}_MATRIX`

  based on predesigned tarballs

  `${MATRIX_folder}/run/run.${process_id}.tar`



Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

- imports
- global definitions
- read command line arguments
  - `class: inputs()`
  - `class: run_class()`
- main part I (setup, readin)
  - → print banner, read `config/MATRIX_configuration`
  - → get name of run & create run-folder/folder structure
  - → get run mode & adjust folder structure accordingly
  - → read input files & set main C++ inputs
  - → set global parameters from read input files (config&run)
  - → assign grids for contributions
- some wrapper functions for actual run
- main part II (actual run)
  - → grid-run → pre-run → main-run
  - → result combination → citation list into `CITATION.bib`
  - → print result summary on-screen → gnuplot

takes care of the running/computing all relevant cross-section contributions after reading the relevant inputs

quite a mess! …almost 6000 lines!

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

read command line arguments

`class: inputs()`

`class: run_class()`

main part I (setup, readin)

- print banner, read `config/MATRIX_configuration`
- get name of run & create run-folder/folder structure
- get run mode & adjust folder structure accordingly
- read input files & set main C++ inputs
- set global parameters from read input files (config&run)
- assign grids for contributions

some wrapper functions for actual run

main part II (actual run)

- grid-run → pre-run → main-run
- result combination → citation list into `CITATION.bib`
- print result summary on-screen → gnuplot

main part of code at the end of the file (last ~800 lines)!

part I: setup of folders and readin of inputs

part II: actual run of all contribution through all stages

Structure of the Matrix scripts

${MATRIX_folder}/bin/run_process

imports

```
#{{{ import own modules
sys.path.append(pjoin(os.path.dirname(os.path.realpath(__file__)),"modules"))
from handle_cluster import *
from handle_lhapdf import lhapdf
from handle_output import banner,output_saver
from handle_folder import which
# import instances of different classes
from initialize_classes import out, prc, log, run_name, edit_input, fold, res, Tee, cite
#import combine_distributions
from handle_gnuplot import gnuplot
```

${MATRIX_folder}/bin/modules/initialize_classes.py

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

`${MATRIX_folder}/bin/modules/handle_input.py`
→ implementes interactive shell, sets name of run, …

`${MATRIX_folder}/bin/modules/handle_output.py`
→ prints banner, handles on-screen output, creates output logfile

`${MATRIX_folder}/bin/modules/handle_folder.py`
→ saves relevant paths, delete/move/clean/tar run folder, …

`${MATRIX_folder}/bin/modules/handle_cluster.py`
→ implements cluster submission for several clusters

`${MATRIX_folder}/bin/modules/handle_lhapdf.py`
→ checks if required set is installed, downloads PDF sets, …

`${MATRIX_folder}/bin/modules/handle_log.py`
→ handles log files during run, creates lock file, …

`${MATRIX_folder}/bin/modules/handle_result.py`
→ creates and fills result folder, includes citations, …

`${MATRIX_folder}/bin/modules/handle_gnuplot.py`
→ creates gnuplot output and plots results into pdf files

…

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

- define allowed processes

```
proper_process_names = ["pph21","ppz01","ppeexa03","ppaa02","ppaaa03",
"ppeex02","ppnenexa03","ppeeexex04","ppemexmx04","ppemxnmnex04","ppexn
ea03","ppenexa03","ppnenex02","ppexne02nockm","ppenex02nockm","ppexne0
2","ppenex02","ppemexnmx04","ppeexmxnm04","pphh22","ppeexexne04","ppee
exnex04","ppeexnenex04", "ppeexnmnmx04","ppzz02","ppw01nockm","ppwx01n
ockm","ppw01","ppwx01","ppwxw02","ppttx20","ppbbx20","pphjj41heft"]
```

- define settings for pre-run (parallelization, number of events)

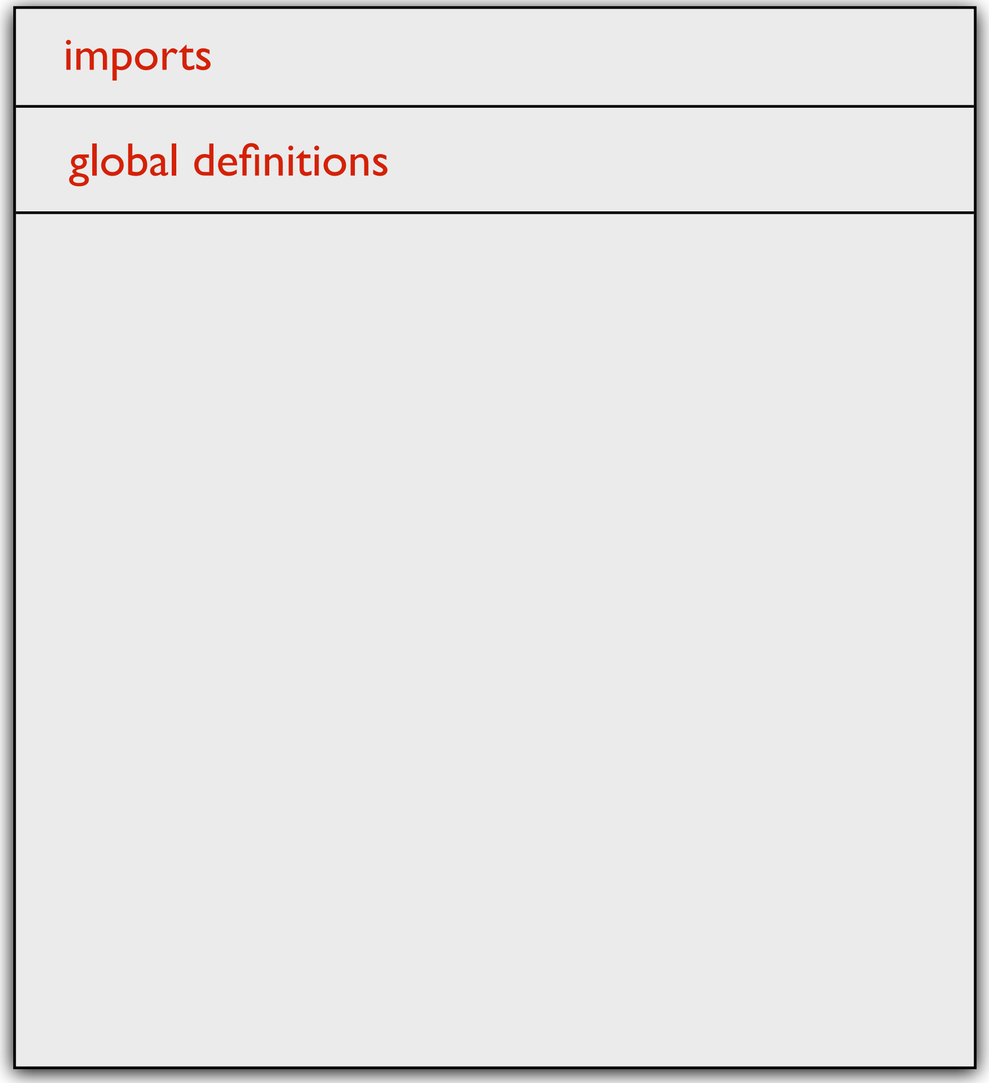
```
 a list [parallelization,events]
default_settings = {}
default_settings["loop"]     = [5,50000]
default_settings["VT2.QCD"] = [5,1000000] # [50,100000]
default_settings["RVA.QCD"] = [1,1000000]  # [10,100000]
default_settings["RRA.QCD"] = [ 1,200000]
```

```
processes_with_involved_settings = ["ppttx20","ppeeexex04","ppemxnmnex
04","ppeexa03","ppnenexa03","ppemexnmx04","ppenexa03","ppexnea03","ppe
mxnmnex04","ppemexmx04","ppeexmxnm04","ppeexexne04","ppeeexnex04","ppe
exnenex04","ppeexnmnmx04","ppzz02","ppwxw02","ppaaa03"]
involved_settings = copy.copy(default_settings)
involved_settings["VA.QEW"] = [25,50000]
involved_settings["VT2.QCD"] = [100,100000]
involved_settings["RVA.QCD"] = [ 20,100000]
```

```
#process specific settings for ppttx20
pre_run_settings["ppttx20"]["RVA.QCD"] = [20,1000000]
pre_run_settings["ppttx20"]["RRA.QCD"] = [5,1000000]
```

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`



- define allowed input parameters of `parameter.dat` file

1. parameters that are identical as in `file_parameter.dat`

```
unique_parameters  = ["process_class","E","coll_choice","scale_fact","
scale_ren","jet_algorithm","jet_R_definition","jet_R","photon_recombin
ation","photon_R_definition","photon_R","photon_E_threshold_ratio","fr
ixione_isolation","frixione_n","frixione_epsilon","frixione_delta_0","
frixione_fixed_ET_max","pdf_content_modify","pdf_selection","define_pT
 missing"]
```

2. parameters that have specific order in `file_parameter.dat`

```
ordered_parameters = ["LHAPDF_LO","PDFsubset_LO","LHAPDF_NLO","PDFsubs
et_NLO","LHAPDF_NNLO","PDFsubset_NNLO"]
# these keywords are defined, so that one can uniquely connect the par
amaters in MATRIX input with the ordered inputs in MUNICH
ord_params_keyword = {"LHAPDF_LO": ["type_perturbative_order","LO","LH
APDFname"],"LHAPDF_NLO": ["type_perturbative_order","NLO","LHAPDFname"
```

3. parameters with different name in `file_parameter.dat`

```
renamed_parameters = ["factor_central_scale","variation_factor","scale_res","dynam
ic_scale_res","factor_scale_res"]
renamed_parameter_mappings = {}
renamed_parameter_mappings["factor_central_scale"] = "prefactor_CV"
```

4. parameters relevant for script (not `file_parameter.dat`)

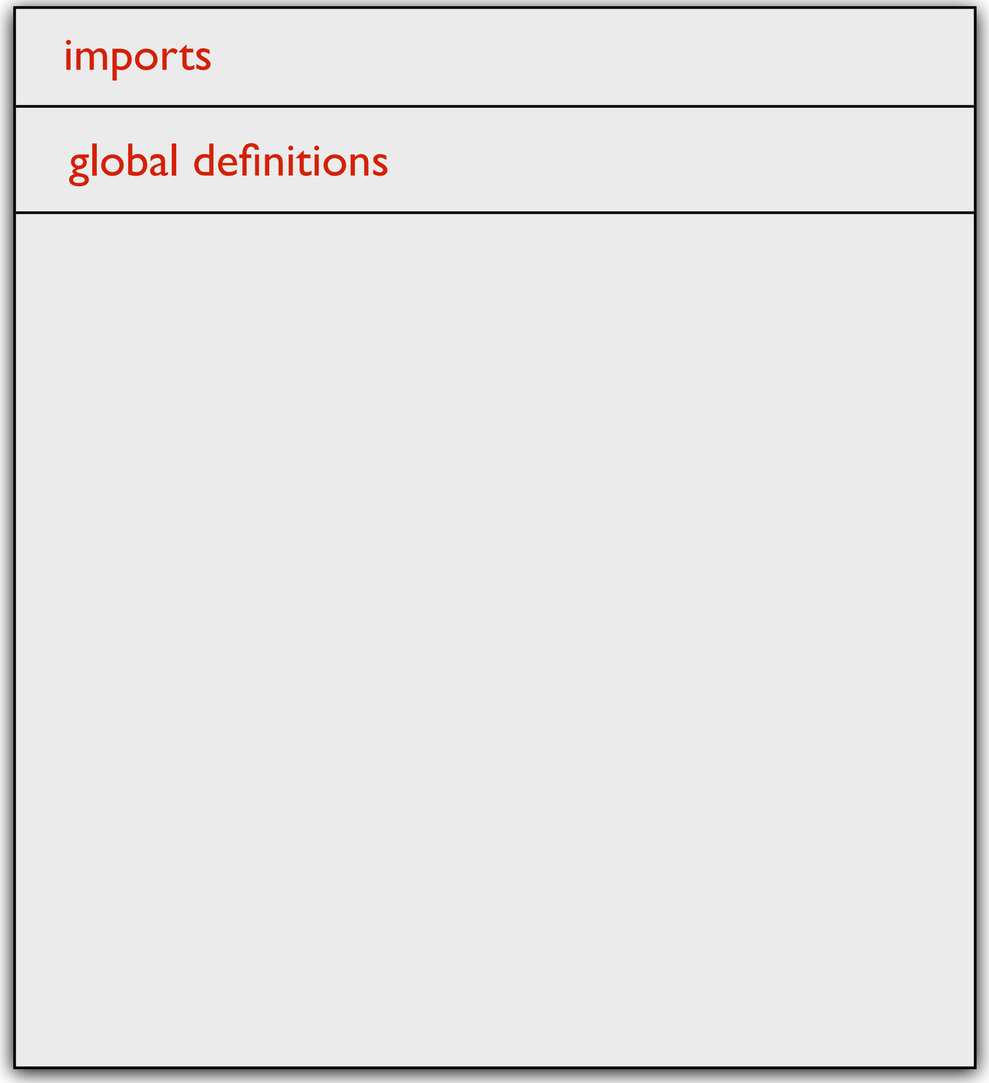
```
MATRIX_parameters  = ["run_LO","precision_LO","run_NLO_QCD","run_NLO_EW","add_NLL"
,"precision_NLO_QCD","precision_NLO_EW","run_NNLO_QCD","add_NLO_EW","add_NNLL","pr
```

5. parameters relevant for script (not `file_parameter.dat`)

```
special_parameters = ["dynamic_scale","switch_distribution","flavor_sc
heme","scale_variation","switch_off_shell","reduce_workload","switch_q
```

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`



- define allowed input parameters of **`parameter.dat`** file

6. process dependent user-defined parameters (cuts)

```
user_parameters["ppeex02"] = ["user_switch M_leplep","user_cut min_M_l
eplep","user_cut max_M_leplep","user_switch R_leplep","user_cut min_R_
leplep","user_switch lepton_cuts","user_cut min_pT_lep_1st","user_cut
min_pT_lep_2nd"]
```

- set parameter that are required to be in **`parameter.dat`** file

```
mandatory_parameters = ["E","coll_choice","save_previous_result","save
_previous_log","NLO_subtraction_method"]
```

- set default values for parameter (if missing in **`parameter.dat`**)

```
default_parameters = {}
default_parameters["NLO_subtraction_method"] = 1 # use CS subtraction
default_parameters["loop_induced"] = 0 # no loop-induced contribution
default_parameters["max_time_per_job"] = 24 # hours
default_parameters["LHAPDF_LO"]    = "NNPDF30_lo_as_0118"
```

- mapping from **`model.dat`** (SLHA format) to **`file_model.dat`**

```
model_mappings_to_MUNICH = multidim_dict(2)
#[Block][number]=parameter_name_in_MUNICH
model_mappings_to_MUNICH["MASS"][1]="M_d"
model_mappings_to_MUNICH["MASS"][2]="M_u"
model_mappings_to_MUNICH["MASS"][3]="M_s"
```

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

read command line arguments

`class: inputs()`

`class: run_class()`

- core classes of entire MATRIX script

`class: inputs()`

```
class inputs():
    """Class to readin user inputs, wrap them and adjust MUNICH inputs"""
```

→ handles all input settings, checks inputs

→ wraps input from **`parameter/model/distribution.dat`** to **`file_parameter/model/distribution.dat`**

→ reads **`config/MATRIX_configuration`**

→ creates all input files for runtime extrapolation and result combination

`class: run_class()`

```
class run_class():
    """Class to run C++ executable of MUNICH in different modes
```

→ handles all running from grid-run over pre-run to main-run

→ handles runtime extrapolation and result combination

→ selects all relevant contributions and subprocesses to be run

→ does cluster submission or multicore mode

→ determines if run is correctly finished and prints alle on-screen output during running

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

read command line arguments

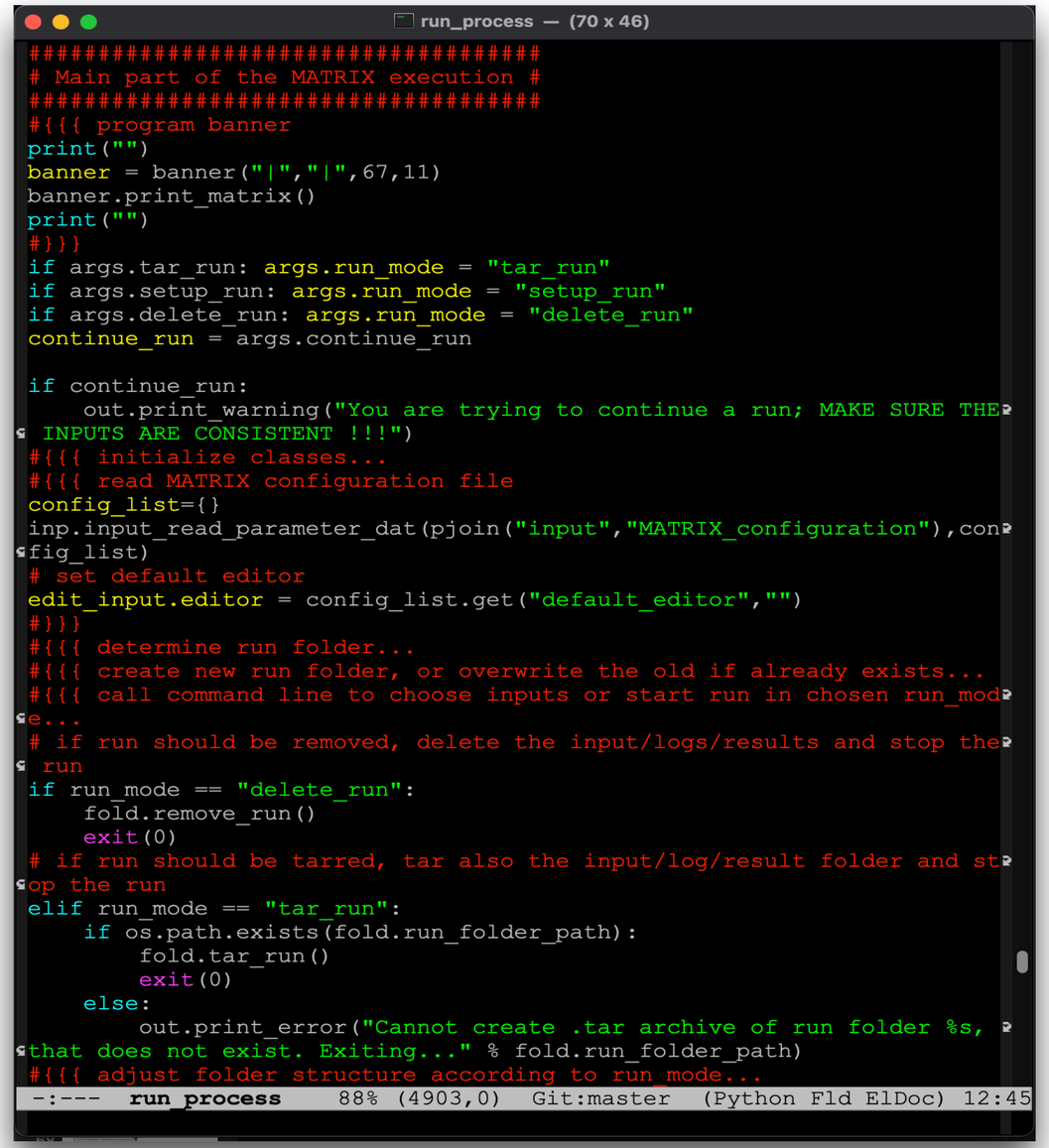
`class: inputs()`

`class: run_class()`

main part I (setup, readin)

- ➙ print banner, read `config/MATRIX_configuration`
- ➙ get name of run & create run-folder/folder structure
- ➙ get run mode & adjust folder structure accordingly
- ➙ read input files & set main C++ inputs
- ➙ set global parameters from read input files (config&run)
- ➙ assign grids for contributions

through interactive interface/ command-line



Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

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read command line arguments

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main part I (setup, readin)

- print banner, read **`config/MATRIX_configuration`**
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- set global parameters from read input files (config&run)
- assign grids for contributions

some wrapper functions for actual run

main part II (actual run)

- grid-run → pre-run → main-run
- result combination → citation list into **`CITATION.bib`**
- print result summary on-screen → gnuplot

run_process

```
############################
# Here start the actual runs #
############################

if not run_mode in ["run_results","run_gnuplot"]:
#### initialize cluster class
    if runmode == "cluster":
        cluster = get_cluster_class_from_name[cluster_name](config_list,verbose)
#### initialize run instance
run = run_class(runmode,grid_folder,main_run_folder,NLO_subtraction,order,set_pa
rallel_runs,grid_assignment,include_loop_induced,config_list)
if run_mode in ["run","run_grid_and_pre","run_grid","run_without_pre"]:
#### run warmup to set up grids
    run.clear_warmup() # clear previous runs in grid dirs
    run.warmup(1) # run warmup
    print_restarted_runs() # if there are any, print out restarted runs
    if run.errors_flag: out.print_warning("Exception error in python jobs while
running warmup.") # check if there were exception errors
    rerun_warmup(max_restarts) # if there are jobs that failed
    check_warmup() # if there are failed grid runs, print warning
    log.move_to_folder(pjoin(fold.log_folder_path,"grid_run")) # move all log fi
les into a new created grid_run folder inside the log folder
if run_mode in ["run","run_grid_and_pre","run_pre","run_pre_and_main"]:
#### extrapolation run (pre run)
    check_grid_log() # check logs if grid_run has been done
    log.clear_list("restarted_list.log") # remover list with restarted jobs
    if run_mode in ["run_pre","run_pre_and_main"]: run.clear_pre_run() # clear p
re run folders of previous runs (already be clean in other runmodes)
    run.main_run(-1) # start pre run
    print_restarted_runs() # if there are any, print out restarted runs
    if run.errors_flag: out.print_warning("Exception error while doing extrapola
tion runs.") # check if there were exception errors
    rerun_pre_run(max_restarts) # if there are jobs that failed
    check_pre_run() # if there are failed pre runs, print error and stop code
    log.move_to_folder(pjoin(fold.log_folder_path,"pre_run")) # move all log fil
es into a new created pre_run folder inside the log folder
    run.extrapolate_runtimes() # extrapolation of runtimes from pre run result
    try:
        run.print_pre_run()
    except:
        pass
    run.read_runtimes() # read in output of extrapolation run
    check_parallel() # check wether the parallelization is not too high
if run_mode in ["run_without_pre","run_main_without_pre"]:
-:**-  run_process     99% (5692,30) Git:master  (Python Fld ElDoc) 12:59am 2.17
```

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

read command line arguments

`class: inputs()`

`class: run_class()`

main part I (setup, readin)

- print banner, read **`config/MATRIX_configuration`**
- get name of run & create run-folder/folder structure
- get run mode & adjust folder structure accordingly
- read input files & set main C++ inputs
- set global parameters from read input files (config&run)
- assign grids for contributions

some wrapper functions for actual run

main part II (actual run)

- grid-run → pre-run → main-run
- result combination → citation list into **`CITATION.bib`**
- print result summary on-screen → gnuplot

run_process

```
if run_mode in ["run","run_main","run_pre_and_main","run_without_pre","run_main_without_pre"]:
#### cross section run (main run)
    if run_mode == "run_main":
        run.read_runtimes() # read in output of extrapolation run
        check_parallel() # check wether the parallelization is not too high
        run.clear_main_run() # clear main run folders of previous runs
    log.clear_list("restarted_list.log") # remove previous restarted job list
    run.main_run(1) # start main run
    print_restarted_runs() # if there are any, print out the restarted runs
    if run.errors_flag: out.print_warning("Exception error while running main processes.") # check if there were exception errors
    rerun_main_run(max_restarts) # if there are jobs that failed
    check_main_run() # if there are still failed main runs, print error and stop
    log.move_to_folder(pjoin(fold.log_folder_path,"main_run")) # move all log files into a new created main_run folder inside the log folder
if run_mode in ["run","run_pre_and_main","run_main","run_results","run_without_pre","run_main_without_pre"]:
#### collect and combine results
    run.clear_results() # remove previous results (if there are any)
    citation_list_run = cite.get_citation_list_run(order,NLO_subtraction)
    citation_list_process = cite.get_citation_list_process(parameter_list)
    citation_list_amplitudes = cite.get_citation_list_amplitudes(parameter_list)
    citation_list_standard = cite.get_citation_list_standard(parameter_list)
    cite.write_citations(pjoin(fold.result_folder_path,"CITATIONS.bib"),parameter_list,citation_list_run,citation_list_process,citation_list_standard=citation_list_standard,citation_list_amplitudes=citation_list_amplitudes)# write citations to file
    run.combine_results() # combine results and distributions and copy them
    out_distributions = ""
    if int(parameter_list["switch_distribution"]) == 1:
        out_distributions = " (including the distributions)" # if distributions
        run_gnuplot() # generate gnuplot output
    run.print_results_onscreen_and_to_summary_file() # write results
    out.print_result("All results%s can be found in:" % out_distributions)
    out.print_result(fold.result_folder_path)
elif run_mode == "run_gnuplot":
    try:
        os.makedirs(pjoin(fold.result_folder_path,"gnuplot"))
    except:
        shutil.rmtree(pjoin(fold.result_folder_path,"gnuplot"))
        os.makedirs(pjoin(fold.result_folder_path,"gnuplot"))
    run_gnuplot() # generate gnuplot output
```

-:**- run_process Top (1,94) Git:master (Python Fld ElDoc) 1:02am 1.64

Structure of the Matrix scripts

`${MATRIX_folder}/bin/run_process`

imports

global definitions

read command line arguments

`class: inputs()`

`class: run_class()`

main part I (setup, readin)

- print banner, read **`config/MATRIX_configuration`**
- get name of run & create run-folder/folder structure
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- read input files & set main C++ inputs
- set global parameters from read input files (config&run)
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some wrapper functions for actual run

main part II (actual run)

- grid-run → pre-run → main-run
- result combination → citation list into **`CITATION.bib`**
- print result summary on-screen → gnuplot

run_process

```
if run_mode in ["run","run_main","run_pre_and_main","run_without_pre","run_main_without_pre"]:
#### cross section run (main run)
    if run_mode == "run_main":
        run.read_runtimes() # read in output of extrapolation run
        check_parallel() # check wether the parallelization is not too high
        run.clear_main_run() # clear main run folders of previous runs
    log.clear_list("restarted_list.log") # remove previous restarted job list
    run.main_run(1) # start main run
    print_restarted_runs() # if there are any, print out the restarted runs
    if run.errors_flag: out.print_warning("Exception error while running main processes.") # check if there were exception errors
    rerun_main_run(max_restarts) # if there are jobs that failed
    check_main_run() # if there are still failed main runs, print error and stop
    log.move_to_folder(pjoin(fold.log_folder_path,"main_run")) # move all log files into a new created main_run folder inside the log folder
if run_mode in ["run","run_pre_and_main","run_main","run_results","run_without_pre","run_main_without_pre"]:
#### collect and combine results
    run.clear_results() # remove previous results (if there are any)
    citation_list_run = cite.get_citation_list_run(order,NLO_subtraction)
    citation_list_process = cite.get_citation_list_process(parameter_list)
    citation_list_amplitudes = cite.get_citation_list_amplitudes(parameter_list)
    citation_list_standard = cite.get_citation_list_standard(parameter_list)
    cite.write_citations(pjoin(fold.result_folder_path,"CITATIONS.bib"),parameter_list,citation_list_run,citation_list_process,citation_list_standard=citation_list_standard,citation_list_amplitudes=citation_list_amplitudes)# write citations to file
    run.combine_results() # combine results and distributions and copy them
    out_distributions = ""
    if int(parameter_list["switch_distribution"]) == 1:
        out_distributions = " (including the distributions)" # if distributions
        run_gnuplot() # generate gnuplot output
    run.print_results_onscreen_and_to_summary_file() # write results
    out.print_result("All results%s can be found in:" % out_distributions)
    out.print_result(fold.result_folder_path)
elif run_mode == "run_gnuplot":
    try:
        os.makedirs(pjoin(fold.result_folder_path,"gnuplot"))
    except:
        shutil.rmtree(pjoin(fold.result_folder_path,"gnuplot"))
        os.makedirs(pjoin(fold.result_folder_path,"gnuplot"))
    run_gnuplot() # generate gnuplot output
```

-:**- run_process Top (1,94) Git:master (Python Fld ElDoc) 1:02am 1.64

How to add a user-defined cut

! check out appendix of Matrix Manual !

- add user parameters (**`user_switch, user_cut`**) to **`parameter.dat`** file of process:

```
user_switch dy_lep1lep2 = 1     #  switch to turn on (1) and off (0) cuts on absolute dy of leptons
user_cut min_dy_lep1lep2 = 0.5  #  requirement on absolute rapidity difference of leptons (lower cut)
```

How to add a user-defined cut

! check out appendix of Matrix Manual !

- add user parameters (**`user_switch`**, **`user_cut`**) to **`parameter.dat`** file of process:

```
user_switch dy_lep1lep2 = 1     #  switch to turn on (1) and off (0) cuts on absolute dy of leptons
user_cut min_dy_lep1lep2 = 0.5  #  requirement on absolute rapidity difference of leptons (lower cut)
```

- add cut inside C++ code under path **`${MATRIX_folder}/prc/ppeex02/user/specify_cuts.cxx`**:

```
// get settings for cut on absolute rapidity difference of leptons
static int switch_dy_lep1lep2     = USERSWITCH("dy_lep1lep2 ");
static double cut_min_dy_lep1lep2 = USERCUT("min_dy_lep1lep2");

// perform cut on absolute rapidity difference of leptons according to settings
if (switch_dy_lep1lep2 == 1){
  double y_lep1 = PARTICLE("lep")[0].rapidity;
  double y_lep2 = PARTICLE("lep")[1].rapidity;
  double dy_lep1lep2 = y_lep1 - y_lep2;
  if (abs(dy_lep1lep2) < cut_min_dy_lep1lep2) {
    osi_cut_ps[i_a] = -1;  // cut phase-space point
    return;
  }
}
```

How to add a distribution

! check out appendix of Matrix Manual !

- put distribution into **`distribution.dat`** file of a process (check out syntax at end of the file):

default.input.MATRIX — less distribution.dat — 109×43

```
##################################
# MATRIX distribution definition #
##################################
#
# In this file you can customize the distributions created during the run (examples below)
# please read the INSTRUCTIONS at the END OF THIS FILE...
#
#------\
# Info |
#------/
# Total rates and jet multiplicities (possibly within cuts) will automatically be included
# Add/remove arbitrary distribution-blocks, but always add/remove a full block.
#
#----------------------\
# define distributions |
#----------------------/

# transverse momentum of the WZ (3-lepton+neutrino) system regularly binned from 0-500 GeV in 10 GeV bins
distributionname  =  pT_WZ
distributiontype  =  pT
particle 1        =  lep 1
particle 1        =  lep 2
particle 1        =  lep 3
particle 1        =  nua 1
startpoint        =  0.
endpoint          =  500.
binwidth          =  10.0
```

```
# pre-defined
# pT
#
# m
# dm
# absdm
# mmin
# mmax
# y
# absy
# dy
# absdy
# dabsy
# absdabsy
#
# eta
# abseta
# deta
# absdeta
# dabseta
#
# absdabseta
#
# phi
#
# dR
# dReta
# ET
#
# mT
```

How to add a user-defined distribution

! check out appendix of Matrix Manual !

- put distribution into **`distribution.dat`** file of a process (check out syntax at end of the file):

```
distributionname  =  y_lep1_plus_y_lep2
distributiontype  =  sum_of_y
particle 1        =  lep 1
particle 2        =  lep 2
startpoint        =  0.
endpoint          =  10.
binwidth          =  0.2
```

- if required distribution does not exist implement new distribution inside C++ code under path **`${MATRIX_folder}/src/observable/xdistribution.cpp`**:

```
...
  else if (xdistribution_type == "sum_of_y}") {
    double sum_y = 0;
    for (int group = 0; group < particles.size(); group++) {
      fourvector fourvector_of_current_reconstructed_particle = reconstructedParticles[group]
      sum_y = sum_y + fourvector_of_current_reconstructed_particle.y();
    }
    observable = sum_y;
  }
...
```

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the **`config/MATRIX_configuration`** file

  ➙ select correct name of cluster (from list of preimplemented clusters)

```
modules — less ../../config/MATRIX_configuration — 109×43
###=================###
## cluster parameter ##
###=================###
# Name of cluster currently supported:
#   slurm, LSF (eg, lxplus), HTcondor, condor_lxplus (special version working on lxplus HTCondor),
#   condor, PBS, Torque, SGE (PSB and Torque/OpenPBS are identical at the moment)
cluster_name = slurm
```

  ➙ select correct name of cluster (from list of preimplemented clusters)

```
# Queue/Partition of cluster to be used for running
#cluster_queue = 2nw
```

  ➙ **NEW:** run can be done directly on the local scratch of cluster nodes (substantially reduces load)

```
# Use local scratch directory to run on cluster (speedup for slow shared file systems):
# 0 -- standard run on shared file system (default)
# 1 -- run in local scratch of nodes; PROVIDE cluster_local_scratch_path BELOW!
# NOT IMPLEMENTED YET: 2 -- run without shared file system; PROVIDE cluster_local_scratch_path BELOW!
cluster_local_run = 0

# Provide a path to the local scratch directories of the nodes
#cluster_local_scratch_path = /PATH/TO/SCRATCH/
```

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the **`config/MATRIX_configuration`** file

  ➙ add a line specific to your cluster/needs/setup to the cluster submit file

```
# add customizable lines at the beginning of cluster submission file
# this allows to add certain cluster-specific requirements as options to the submission
# eg: cluster_submit_line1 = "#SBATCH --mem-per-cpu=4000"
#     to increase the memory of a slurm job on certain clusters
# or you can add commands to the bash commands to source or export stuff on the nodes:
# eg: cluster_submit_line2 = "source /PATH/"
# or: cluster_submit_line3 = "export YOUR_FAVOURITE_VARIABLE=/PATH/"
#
# You can add as many lines as you want of the structure "cluster_submit_lineX", where X
# is a number which defines the order of the lines added to the submission file.
# If you want/need to use "#", "%" or "=" signs you need to put quotes around the line: "#blah" !
#cluster_submit_line1 = "line 1 added to submission file"
#cluster_submit_line2 = "line 2"
#cluster_submit_line3 = "line 3"
#       ...          =   ...
# If you need to use quotes in your command you can use:
#cluster_submit_line1 = """variable = "this_has_to_be_in_quotes""""
```

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the `config/MATRIX_configuration` file
- any major change to the cluster setup has to be done directly inside `bin/module/handle_cluster.py`

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the **`config/MATRIX_configuration`** file
- any major change to the cluster setup has to be done directly inside **`bin/module/handle_cluster.py`**

  ➙ there is a **`class cluster_basic()`** and one class for each implemented cluster

handle_cluster.py

```
#{{{ imports...

#{{{ def: make_executable...
#{{{ class: cluster_basic(object)...
#{{{ class: slurm_cluster(cluster_basic)...
#{{{ class: condor_cluster(cluster_basic)...
#{{{ class: condor_lxplus_cluster(cluster_basic)...
#{{{ class: HTcondor_cluster(cluster_basic)...
#{{{ class: lsf_cluster(cluster_basic)...
#{{{ class: pbs_cluster(cluster_basic)...
#{{{ class: sge_cluster(cluster_basic)...

get_cluster_class_from_name = {'condor': condor_cluster,'HTcondor': HTcondor_cluster,'condor_lxplu
s': condor_lxplus_cluster, 'LSF': lsf_cluster, 'slurm': slurm_cluster, 'PBS': pbs_cluster, 'Torque
': pbs_cluster, 'SGE': sge_cluster}
```

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the **`config/MATRIX_configuration`** file
- any major change to the cluster setup has to be done directly inside **`bin/module/handle_cluster.py`**

  ➞ **`class cluster_basic()`** includes all routines (dummy & shared) required to submit runs on cluster

handle_cluster.py

```
#{{{ class: cluster_basic(object)
class cluster_basic(object): # basic class that handles all cluster types
    cluster_name = "basic cluster class"
#{{{ def: __init__(self)...
# cluster dependend functions:
#{{{ def: get_list_queue_command_with_multiple_ids(self,job_ids)...
#{{{ def: create_batch_file(self,job_name,batch_file_name,run_path,process,subprocess_in_path,subprocess_out_path,subprocess_err_path)...
#{{{ def: submit_to_cluster(self,batch_file_name)...
#{{{ def: get_job_id_from_content_of_submit_output(self,content)...
# functions that are needed only for certain clusters:
#{{{ def: create_cd_script(self)...
#{{{ def: create_local_run_script(self)...
#{{{ def: get_list_command_for_single_job_id(self,job_id)...
#{{{ def: modify_request_by_grepping_job_ids(self,request,job_ids)...
```

How to add/adjust a cluster

- small adjustments to the cluster setup can be done via the **`config/MATRIX_configuration`** file
- any major change to the cluster setup has to be done directly inside **`bin/module/handle_cluster.py`**

  ➙ **`class ${name}_cluster()`** inherits from **`cluster_basic()`** and overwrites cluster-specific functions

handle_cluster.py

```
class slurm_cluster(cluster_basic): # class for slurm cluster inherited from basic cluster class
    cluster_name = "slurm"
#{{{ def: __init__(self,config_list,verbose)
    def __init__(self,config_list,verbose):
        cluster_basic.__init__(self,config_list,verbose)
        self.command_kill_job = "scancel"
        try:
            self.command_list_queue = ["squeue","-p","%s" % self.config_list["cluster_queue"]]
        except:
            self.command_list_queue = ["squeue"]
        current_user = getpass.getuser()
        self.command_list_queue_current_user = ["squeue","-u",current_user]
        self.command_list_queue_with_jobid = ["squeue","-j"]
        self.job_status_list = [" PD "," R "," *not set* "," *not set* "]
#}}}
#{{{ def: get_list_queue_command_with_multiple_ids(self,job_ids)...
#{{{ def: create_batch_file(self,job_name,batch_file_name,run_path,process,subprocess_in_path,subp
rocess_out_path,subprocess_err_path)...
#{{{ def: submit_to_cluster(self,batch_file_name)...
#{{{ def: get_job_id_from_content_of_submit_output(self,content)...
```